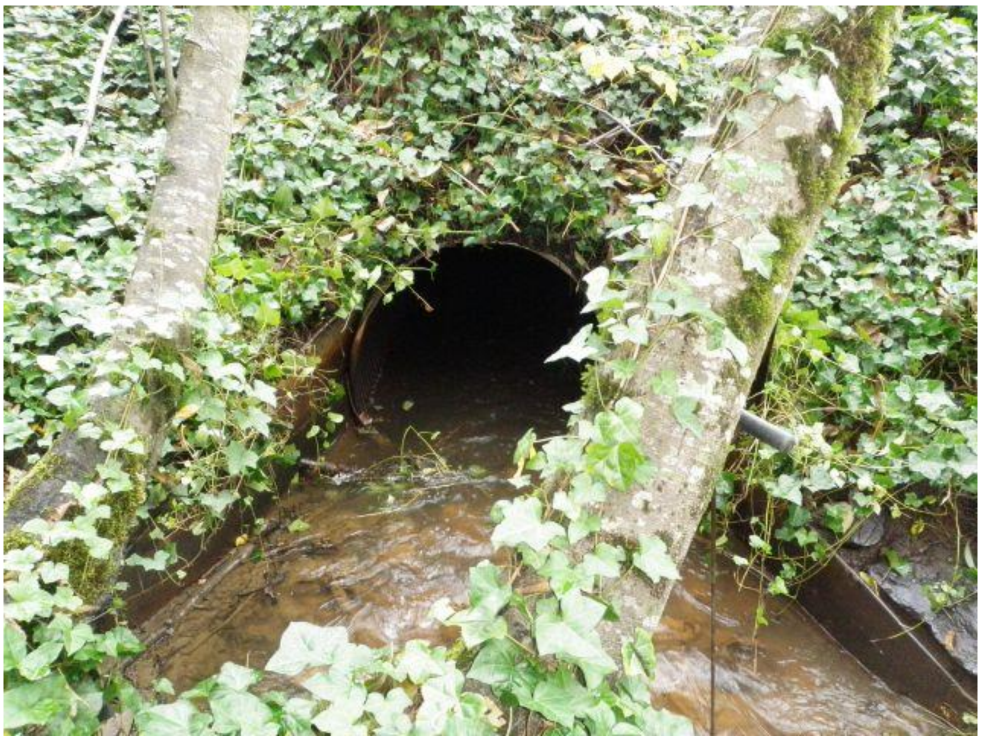
I-90 MP 16.21 Unnamed Tributary to Tibbetts Creek

(WDFW ID: 991182)

Preliminary Hydraulic Design Report



JULIE HEILMAN, P.E.
STATE HYDRAULIC ENGINEER
WSDOT HQ HYDRAULICS OFFICE

RAY WALTON, Ph.D., P.E., D.WRE, F. ASCE, (FPT20-10476) PROJECT MANAGER, WEST CONSULTANTS, INC.
TODD BENNETT, P.E., (FPT20-38257) PRINCIPAL, NHC
ALEX ANDERSON, P.E., (FPT20-33848) SENIOR ENGINEER, NHC
TYLER ROCKHILL, P.E., (FPT20-07858) STAFF ENGINEER, NHC
ANNIE DUFFICY, (FPT20-38157) WATER RESOURCE SCIENTIST, NHC

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1 Introduction

To comply with United States, et al vs. Washington, et al No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas (WRIAs) 1-23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the Interstate 90 (I-90) crossing of Unnamed Tributary to Tibbetts Creek at Mile Post (MP) 16.21. This existing structure on I-90 has been identified as a fish barrier by Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (Site ID 991182) and has an estimated 2,713.25 LF of habitat gain.

Per the injunction, and in order of preference, fish passage should be achieved by (a) avoiding the necessity for the roadway to cross the stream, (b) use of a full span bridge, or (c) use of the stream simulation methodology. WSDOT evaluated the crossing and determined the use of stream simulation methodology is applicable to this crossing.

The crossing is located within the City of Issaquah, WA in WRIA 8. The highway runs east-west at this location and is about 4,165 feet from the confluence with Tibbetts Creek. Unnamed Tributary to Tibbetts Creek generally flows north to south beginning upstream of the I-90 crossing, then turns to flow east to west downstream of the crossing (see Figure 1 for the vicinity map). The Unnamed Tributary has also been called Pickering Creek, notably by the Lake Sammamish Kokanee Working Group (KWG).

The proposed project will replace the existing 376-foot-long, 4-ft diameter circular corrugated steel culvert with a structure designed to accommodate a minimum hydraulic opening of 17 feet. The proposed structure is designed to meet the requirements of the federal injunction using the Stream Simulation design criteria as described in the 2013 WDFW Water Crossing Design Guidelines (WCDG). This design also meets the requirements of the WSDOT Hydraulics Manual. A structure type has not been recommended; structure type will be determined at a later phase.

The design of this crossing includes consideration of the Gilman Boulevard Overflow from Issaquah Creek (FEMA, 2010), which considers significantly higher flows than are generated from the Unnamed Tributary to Tibbetts Creek. All design criteria considers the overflows, but structural, stability, and floodplain regulatory components of the crossing were specifically designed to meet the requirement of the overflow events, while habitat and fish use criteria were designed utilizing flows generated by the Unnamed Tributary to Tibbetts Creek.

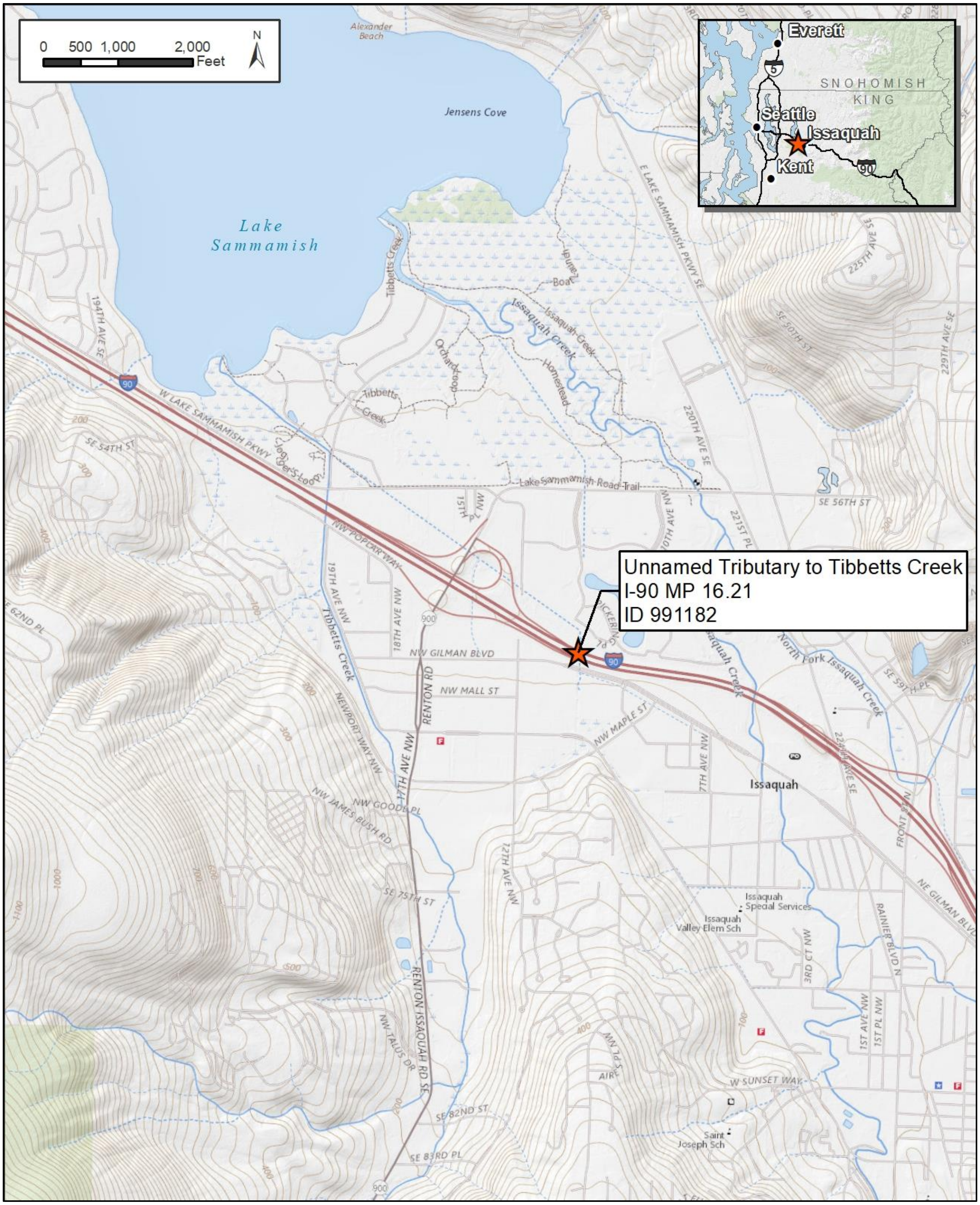

Figure 1: Vicinity map

2 Watershed and Site Assessment

2.1 Watershed and Landcover

I-90 crosses the northern channel of the Unnamed Tributary to Tibbetts Creek, also referred to as Pickering Creek, approximately 0.5 miles upstream of its confluence with the southern Unnamed Tributary in the I-90 and SR 900 interchange (Figure 2). Since coordination is required between crossings I-90 MP 16.21, I-90 MP 16.03, I-90 MP 15.82, I-90 MP 15.89, I-90 MP 15.92 and I-90 EB Ramp MP 15.92, and all crossings are technically on "Unnamed Tributary to Tibbetts Creek" the northern channel and southern channel distinction was made (Figure 2). The channel crosses I-90 0.8 miles upstream of its confluence with Tibbetts Creek and 1.2 miles from Tibbetts Creek mouth where it enters Lake Sammamish. The watershed of the contributing basin above the project crossing was delineated from known stormwater routing system information in the highly urbanized area. The contributing basin (Figure 3) has an area of about 0.41 square miles with a maximum elevation of 387 feet in the basin uplands and descends to about 50 feet at the crossing. The overall basin has gentle slopes with an average basin slope of six percent. The creek is channelized through a commercialized urban corridor for most of its length with limited floodplain accessibility until the confluence with Tibbetts Creek. According to an analysis of the available aerial imagery, the stream was channelized before 1936, flowing through what was mostly cleared farmland until basin-wide urban development began in earnest during the 1980s. The channel was realigned downstream of I-90 in the 1980s from its original route along what is now 11th Avenue to its current corridor along I-90 westbound. Based on the National Land Cover Database (NLCD) dataset (Yang et al., 2018), landcover in the basin is dominated by urban development (90 percent), with 60 percent of that representing moderately to highly developed areas, and the remaining 10 percent occupied by mixed forest and herbaceous plants, most of which is in the residential area in the upper basin. On average, 41.4 inches of precipitation falls on the basin annually (PRISM Climate Group, 2019).

Figure 2: Zoomed-in vicinity map of the Unnamed Tributary to Tibbetts Creek in the I-90 and SR 900 interchange area

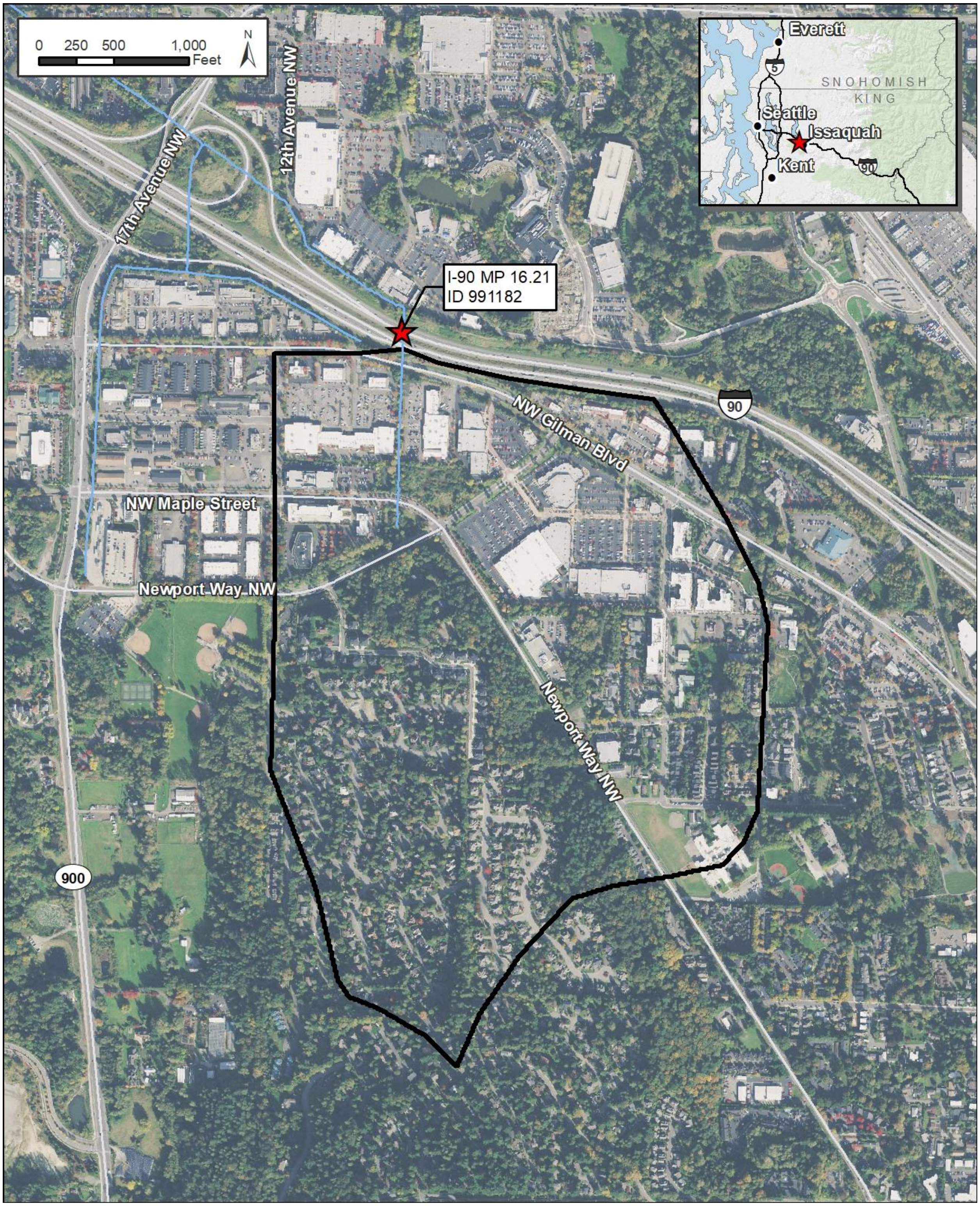

Figure 3: Basin land use in the northern Unnamed Tributary to Tibbetts Creek

2.2 Geology and Soils

The surficial geology of the Tibbetts Creek unnamed tributary basin reflects the landscape's continued evolution from glacial erosion and deposition during the last ice age followed by the present era defined by anthropogenic alterations to the landscape. Glacial drift deposits and glacial till from the most recent glacial advance define the hillslopes in the upper basin of the tributary. During the Vashon advance of the Fraser glaciation, ice flowed from British Columbia into the Puget Lowlands to form the Puget lobe of the Cordilleran ice sheet (Booth et al., 2002). Ice contact deposits represent deposition against stagnant melting ice in the glacial Lake Sammamish trough and are found in the highlands of the basin. The drift deposits consist of a high percentage of silt intermixed with granular sediments that result in poorly sorted stratified sediment. The lowlands of the greater Tibbetts and Issaquah Creek basins are characterized by low gradient alluvial and wetland deposits forming since the retreat of the glaciers after the last ice age (Booth et al., 2012). The headwaters of the Unnamed Tributary appear to begin in the basin lowlands of mostly bog and peatland deposits, flowing through a very narrow urban corridor in the mapped peatland deposits until the crossing under I-90, after which the stream flows through modified alluvium along I-90. Bogs regularly overly impermeable clay layers, which prevents drainage into groundwater. This clay layer is exposed in the bed and banks downstream of I-90 (Figure 4).

Figure 4: View of clay material that defines the bed and banks downstream of I-90

Based on historical aerial image analysis, the stream was disconnected from the historic floodplain during channelization in the early 20th century and continues to be affected by the lack of floodplain connectivity in the existing narrow urban corridor. Stormwater inputs from local urban runoff do not appear to be a good source of coarse sediment to the stream (Figure 5). Local supply to the channel from the bed and banks consists of clay and fine-grained alluvium, both of which contribute to the high suspended sediment load. These fine materials do not provide significant coarse sediment supply to the creek.

Figure 5: View of culvert 80 feet upstream of the project culvert inlet (WDFW ID# 920193) and the gray coloring characteristic of stormwater runoff (blue arrow indicates flow direction) (Station 13+80)

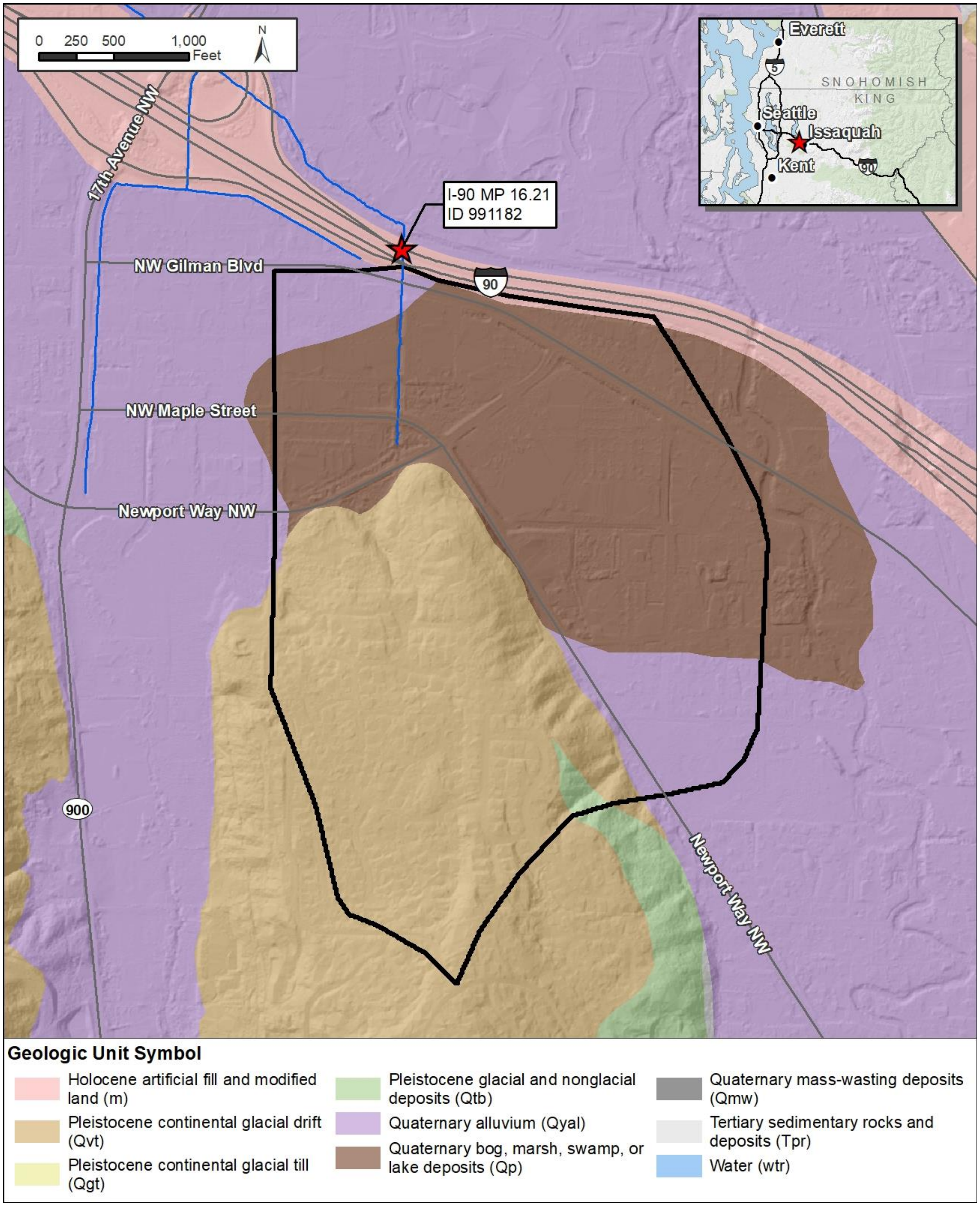

Figure 6: Basin surficial geology of the northern Unnamed Tributary to Tibbetts Creek

2.3 Floodplains

This project is not within a mapped floodplain; however, the upstream end is immediately adjacent to the end of a detailed study (FEMA, 2010) and the Gilman Boulevard Overflow was considered as impacting this project (Appendix A - FEMA Floodplain Map). The Gilman Boulevard Overflow occurs when Issaquah Creek overflows its banks upstream of Gilman Boulevard, which itself is upstream of I-90 (occurs at events larger than the 10-year recurrence interval). The flood flow travels west north-west along a series of large ditches to a 4-foot culvert that joins the I-90 MP 16.21 crossing at a manhole at Sta. 13+88. The pre-project and expected post-project conditions were evaluated to determine whether or not there would be a change in water surface elevation and floodplain storage (See Section 6).

2.4 Site Description

I-90 MP 16.21 Unnamed Tributary to Tibbetts Creek (WDFW ID: 991182) is listed as a barrier due to velocity. The largest detriment to fish habitat is the length of the culvert; at 376 feet long and 4 feet in diameter, there are little to no rest or holding areas available. This crossing is not listed as a Chronic Environmental Deficiency (CED) or failing structure. No maintenance activity was visible during the site visit and the maintenance log for this crossing did not indicate prior maintenance activity. The total length of habitat gain for this crossing is 2,173 linear feet.

2.5 Fish Presence in the Project Area

Table 1 provides a list of native fish that are potentially found in Unnamed Tributary to Tibbetts Creek. Fish distribution information was gathered from the Statewide Washington Integrated Fish Distribution (SWIFD) dataset (WDFW, 2019), managed by WDFW and NW Indian Fisheries Commission (NWIFC), and the WDFW fish passage reports (WDFW, 2019). Winter Steelhead and Fall Chinook found in Unnamed Tributary to Tibbetts Creek are listed as Threatened under the Endangered Species Act of 1973, as part of the Puget Sound Distinct Population Segment. Coho found in Unnamed Tributary to Tibbetts Creek are listed as a Species of Concern by following procedures in Washington Administrative Code 220-610-110. Cutthroat Trout and Coho were observed at the crossing in 2012 (WDFW, 2012).

Table 1: Native fish species potentially present within the project area

Species	Presence (Presumed, Modeled, or Documented)	Data Source	ESA Listing
Sockeye	Documented	SWIFD, RSFS	Not Listed
Kokanee	Documented	SWIFD. RSFS	Not Listed
Coho	Documented	SWIFD, RSFS	Species of Concern
Winter Steelhead	Presumed	SWIFD, RSFS	Threatened
Searun Cutthroat	Presumed	PHS, RSFS	Not Listed
Resident Trout	Presumed	PHS, RSFS	Not Listed
Fall Chinook	Modeled	SWIFD	Threatened

2.6 Wildlife Connectivity

WSDOT will indicate whether this is a high, medium, or low wildlife priority route at a later date. Final Design will incorporate wildlife connectivity if needed.

2.7 Site Assessment

2.7.1 *Data Collection*

Northwest Hydraulic Consultants (NHC) visited the project site on May 14, 2020 to measure the Bankfull Width (BFW) of Unnamed Tributary to Tibbetts Creek and collect pertinent information to support the basis of design, the results of which are summarized in Appendix B. NHC measured an average BFW of approximately nine feet during the site visit (see Appendix B and Section 2.8.2). Due to COVID 19 restrictions, a site visit with WSDOT, WDFW, and the Tribes was not possible and thus the BFW represents the agreed-upon number by the NHC team alone. The engineers and geologist observed local stream and valley terrain conditions 1,000 feet downstream and 500 feet upstream of the existing structure under I-90 and Gilman Boulevard. Multiple pebble counts (PC) were measured in the field, one upstream and three downstream of the crossing, including two in the designated reference reach, and are summarized in Section 2.8.3.

2.7.2 *Existing Conditions*

The existing structure consists of a 376-foot long, 4-foot diameter single broken-back corrugated metal culvert at a 0.56 percent slope (Figure 7). The culvert includes a manhole approximately eight feet downstream from the inlet that allows a second 4-foot diameter culvert to enter the Unnamed Tributary to Tibbetts Creek. The second culvert also occurs at a slope break, creating the broken back. The source of that culvert drains the developed area to the east and is the primary closed conveyance for Issaquah Creek overflows. There is an additional 4-foot diameter culvert 60 feet upstream of the crossing (Figure 8). The project culvert crosses under Gilman Boulevard and I-90 before daylighting downstream. The outlet has a wing wall and there is a small ditch entering from the east (Figure 9). The outlet has formed a scour pool that is approximately three feet below typical grade.

Figure 7: Existing conditions at the I-90 culvert inlet (blue arrow shows flow direction) (Sta. 13+80)

Figure 8: Outlet of WDFW culvert 920193 (Sta. 14+50)

Figure 9: Existing conditions at the I-90 culvert outlet (blue arrow shows flow direction) (Sta. 10+00)

NHC walked 400 feet upstream of the I-90 MP 15.82 culvert observing stream and riparian conditions across the two culvert crossings immediately upstream (WDFW Culvert ID 920193 and 920194). A steep narrow ditch conveys flow upstream. The channel is mostly straight, achieving minor low flow bends within the narrow 60-ft corridor bound on either side by concrete parking lots of the commercial shopping area (Figure 10). The channel is only about four to five feet wide upstream, bound by steep overbank slopes densely vegetated with fern, horsetail, reed canary grass, English ivy, and mature trees present between WDFW Culvert 920193 and the project culvert inlet. The channel bed reflects this transition to a denser canopy, as mobile wood-forced riffles and pools become more prevalent in the overall glide-dominated stream (Figure 11). NHC conducted a pebble count on one of these sandy gravel riffle beds to characterize the approximate bedload composition available to the reach downstream of I-

90. This tributary conveys stormwater from the surrounding urban area, causing gray discoloration of the stream water (Figure 8).

Figure 10: View of confined northern unnamed tributary to Tibbetts Creek corridor upstream of Culvert 920194 (blue arrow indicates flow direction)

Figure 11: Channel conditions in the reach between the I-90 culvert inlet and Culvert 920193 (blue arrow indicates flow direction, white arrow indicates wood jam) (Sta. 14+02)

Downstream of the crossing, the Unnamed Tributary to Tibbetts Creek takes a 90 degree bend to the northwest and passes through a confining cross-section where the channel becomes shallow and narrow. I-90 eastbound on the left bank and commercial property on the right bank constrain the channel downstream within a 100-ft wide corridor (Figure 12). The channel is entrenched two feet below a vegetated channel bench that accommodates higher flows. NHC observed clay channel bed and banks downstream of I-90 with limited gravel alluvial cover on the channel bed (Figure 13). The channel alternates between riffle-glide and glide morphology. The increasing presence of large woody material (LWM) controls hydraulic and morphologic complexity downstream, as wood-forced riffle-pool sequences help establish gravelly bed substrate in the clay-rich bed and banks and BFW widens from five to nine feet (Figure 14). Fine sediment has accumulated in the plunge pools, which are scoured into the clay substrate. The stream has undergone some restoration downstream of I-90 through the installation of LWM, including toe logs, notched log weirs (Figure 15), and habitat logs (Figure 16). Installed LWM is anchored with cable and consists of logs between one- to two-foot DBH. The stream crosses under a pedestrian bridge at Station 06+50 (Figure 17) and then flows through a 4-foot diameter private culvert (WDFW ID: 920196) that transitions to a 3-foot high by 5-foot wide concrete box culvert (Figure 18). This culvert crosses under the corner of a driveway and is of unknown passability, a Level B analysis is required. During the FHD phase, PEO should determine culvert owner and assess possibility of removal due to private crossing hydraulic impact and limited need for the culvert.

Figure 12: View of channel corridor 100 feet downstream of 1-90 culvert outlet, with Big Lots bordering the right bank and I-90 westbound off ramp on the left bank behind dense blackberry (blue arrow indicates flow direction, white arrow points to anchored wood on the bank)

Figure 13: Exposed clay bed with little alluvial cover downstream of I-90 (Sta. 03+50)

Figure 14: Example of riffle-glide morphology through the restoration reach (Sta 03+97)

Figure 15: Notched log weir structure under shaded canopy (Sta. 03+16)

Figure 16: Typical anchoring on LWM through the restoration reach (Sta. 01+75)

Figure 17: Pedestrian footbridge at Sta. 02+50

Figure 18: Downstream city culvert WDFW ID 920196 (Sta 00+00)

2.7.3 *Fish Habitat Character and Quality*

Downstream of the crossing there is a reach that has had some restoration work done primarily in the form of LWM installation; the results of this work have increased hydraulic complexity, adding some deeper pools and well-formed riffles to the typical morphology. Riparian cover consists of mostly reed canary grass for the first 200 feet downstream of I-90, transitioning to a mix of trees, woody shrubs, and grass and becoming more tree-rich closer to the city culvert inlet 1,000 feet downstream of I-90. LWM is present in low densities. Habitat in the grass dominated reach is limited by lack of shading, complexity, and refuge, as LWM is mostly absent. Upstream of the crossing also lacks complexity and is dominated by glides, although some plunge pools are forced by small wood jams. Small gravel is present throughout the system interspersed between patches of fine deposits and exposed clay bed. Further upstream of the crossing there is a palustrine wetland complex that could provide rearing habitat for juvenile salmonids (WDFW, 2008) if water quality parameters are within suitable ranges.

The Lake Sammamish Kokanee Working Group has identified the Unnamed Tributary to Tibbetts Creek (aka Pickering Creek) for restoration projects that include removal of riprap, addition of LWM, and native vegetation planting. Kokanee have also been observed in the Unnamed Tributary to Tibbetts Creek; for example, eleven kokanee were observed in the reach between the I-90 culvert to 12th Avenue on a spot check on December 12, 2012 (LSKWG, 2014). Since there are no steep headwaters in the Unnamed Tributary to Tibbetts Creek, migration and juvenile rearing habitats are the priority life stage habitats applicable to this crossing. Spawning habitat improvements would require reduction of fines and creation of clean gravel habitats, likely facilitated through the addition of LWM to force more channel and floodplain complexity as well as pool formation. Riparian planting should discourage reed canary grass. Since this reach has been artificially confined, improving floodplain connectivity and increasing the floodplain utilization ratio is a priority design objective.

2.8 Geomorphology

2.8.1 *Reference Reach Selection*

The I-90 Tibbetts Creek tributary crossing is in a region that is affected by ongoing channel adjustments resulting from urbanization, channel realignment, and channelization. Most of the observed reach upstream of the crossing is highly confined laterally by steep overbank slopes of densely vegetated invasive shrubs and vines, resulting in narrowly entrenched channel conditions. The stream within the vicinity of the I-90 crossing maintains a slope between 0.4 and 0.6 percent, with some minor deviations from that slope in the numerous culvert crossings upstream of the crossing. While the creek downstream of I-90 remains laterally confined within an urban corridor, the available floodplain increases by 40 feet, resulting in a more natural channel cross-section. The channel remains entrenched for most of the downstream extent, but a wider channel bench accommodates higher flows. Downstream of I-90, channel complexity increases in the form of riffle-pool bed morphology, higher sinuosity, and greater instances of LWM. This segment of the tributary maintains a 0.45 percent slope, making it an appropriate reference reach for this crossing. See Figure 19 for an aerial view of the reach.

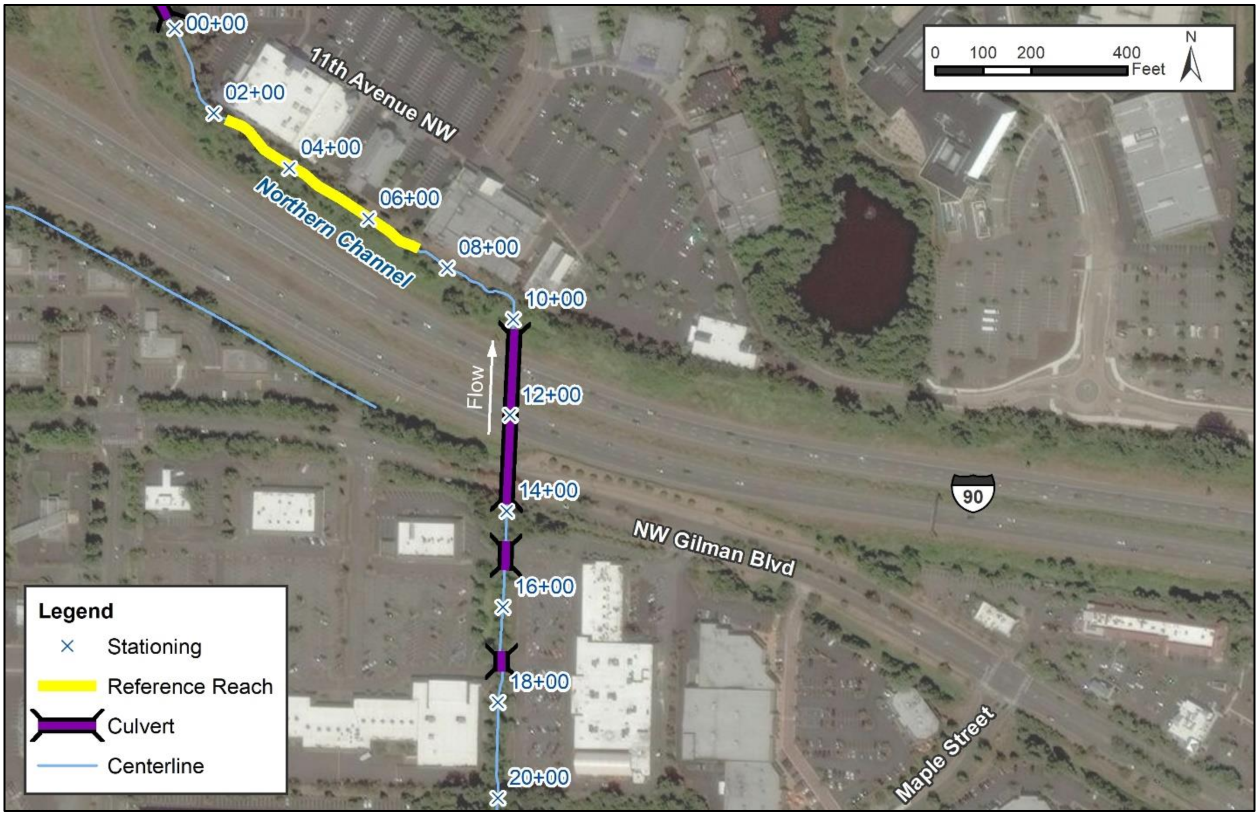

Figure 19: Reference reach

NHC selected the reach between Station 02+00 and 7+00, which is a previously restored channel recommended by the Lake Sammamish Kokanee Working Group as a model reference reach for kokanee habitat restoration. This area is also referred to as the 12th Ave restoration reach of Pickering Creek, located behind the PetSmart on 12th Avenue. Thisreach contains engineered LWM, complex bed morphology, and a diverse riparian corridor with restored native plantings (Figure 20). LWM is anchored both along channel banks and constructed into notched log weirs with an average DBH of one foot. Most importantly, the wood is placed in a single-piece design instead of racked jams. Single-piece design reduces the likelihood of creating small-mouth bass predatory habitat. Wood-forced riffle pool morphology has encouraged gravel substrate beds in these hydraulically roughened areas (Figure 21). Scour from wood-forced channel constrictions and roughness elements have also widened the stream and decreased channel bank slopes in the entrenched corridor. Channel sinuosity increases in the reference reach as compared to the mostly straight channel upstream of I-90. NHC measured channel sinuosity of 1.1 in the field, defined as the ratio of total channel length to the corridor length. Though this reach has been enhanced through restoration efforts, it does not meet the requirements of a reference reach. This reach is still confined by floodplain development and is impacted by adjacent culvert crossings, both hydraulically and through sediment disruptions. Therefore this reach is considered a design reach, but not a reference reach.

Figure 20: Photo of reference reach, looking downstream (blue arrow indicates flow direction) (Station 03+15)

Figure 21: Photo of natural wood and characteristic coarse grains of a riffle bed in the reference reach at Sta. 04+45 (blue arrow indicates flow direction)

2.8.2 *Channel Geometry*

The northern channel of the Unnamed Tributary to Tibbetts Creek is a mostly straight channelized stream above I-90 at a gradient of 0.5 percent. The creek is currently entrenched and laterally confined by vegetated steep overbank slopes within a narrow 60-ft urban corridor. Average BFW between the I-90 culvert and WDFW Culvert ID 920193 is five feet accompanied by steep banks, yielding a channel width to depth ratio of 5:2 in this 60-ft long reach (Figure 22, Station 14+30 in Figure 23). Overbank slopes are slightly shallower upstream of WDFW Culvert ID 920194 and BFW increases to six feet in the reach encroached by reed canary grass (Station 18+70 in Figure 23). Channel position is fixed upstream of I-90, confined by the steep embankments of the narrow corridor, resulting in a straight stream. The corridor lacks a channel bench upstream of I-90 to accommodate higher flows.

Figure 22: Channel conditions upstream of I-90 culvert (blue arrow shows flow direction) (Sta. 14+02)

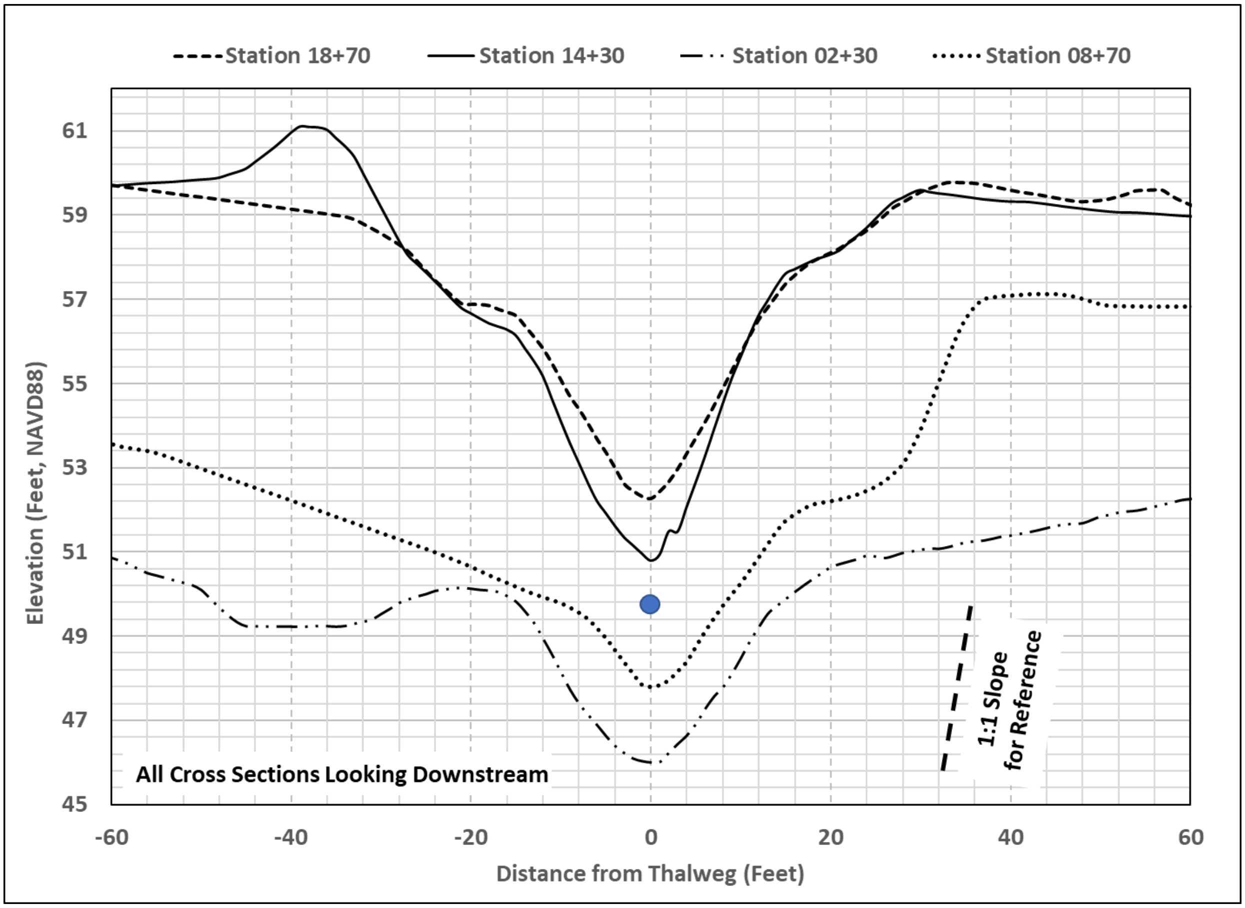

Figure 23: Existing cross-section examples (blue ellipse represents I-90 culvert to separate upstream and downstream cross-sections)

Downstream of I-90, the stream flows through a 100-ft wide corridor bound by the I-90 road embankment on the left-bank floodplain and a commercial shopping center on the right-bank floodplain. The channel is entrenched two to three feet below a grassy bench that is most prominent on the right bank of the stream (Figure 24, Station 08+70 in Figure 23). The BFW is about eight feet for the first 100 feet downstream of I-90 (Figure 24). The channel widens downstream in the reference reach as natural and engineered LWM creates local constrictions and downstream bank scour, increasing average width from 8 to 9.5 feet (Figure 25). The average width to depth ratio downstream is 9:3 and the average channel slope is 0.45 percent, the design gradient for the regrade. A high-flow channel appears about 300 feet upstream of the city culvert (WDFW Culvert ID 920196, shown in Figure 2 and Figure 18) on the left bank that bypasses the city culvert and directs flow to the tributary downstream (Station 08+70 in Figure 23). The channel widens in the densely wooded restored reach obtaining more shallow bank slopes (Station 02+30 in Figure 23, Figure 25). Channel sinuosity also increases downstream of I-90 from 1 upstream of the culvert to 1.1 as channel complexity improves from LWM additions.

Figure 24: Channel conditions immediately downstream of I-90 culvert outlet (blue arrow indicates flow direction) (Sta. 09+50)

Figure 25: Channel conditions in the restored reach (blue arrow indicates flow direction) (Sta. 01+75)

Bankfull width measurements were taken in three locations downstream of I-90 to inform channel design. Measurements are summarized in Table 2 and labeled in Figure 26. The average and median of the three BFW measurements was 9.0 feet, which the NHC team from the site visit agreed on as the design BFW. However, an agreed-upon BFW with WDFW, the Tribes, and WSDOT has yet to be determined. Estimating BFW from the WDFW regression equation yields an expected channel width of seven feet. Average wetted top widths from the natural condition hydraulic model (Section 4) for the 2-year recurrence interval event range from 8 feet to 28 feet, with an average of 18 feet. However, development within the basin and tendency for the 2-year to overestimate bankfull flows (Castro and Jackson, 2001) may explain the difference between observed bankfull widths and simulated bankfull width. Sediment transport efficiency is conserved throughout the observed reach downstream of I-90, especially in the 0.45 percent reference reach that contains coarse riffle bed deposits. Bank strength downstream is high, controlled by cohesive and vegetated clay banks. It is important to remember that stormwater runoff is added downstream of the I-90 crossing. To tie-in to the narrow upstream channel, a top width of nine feet is appropriate if a bottom width does not exceed five feet, the average BFW upstream. The success of the crossing relies on the crossing channel maintaining bank strength to avoid over-widening, and thus avoiding invasive reed canary grass colonization of the bed. Therefore, sufficient shear stress should be achieved on the bed, while maintaining appropriate depth for fish passage by engineering heightened bank strength.

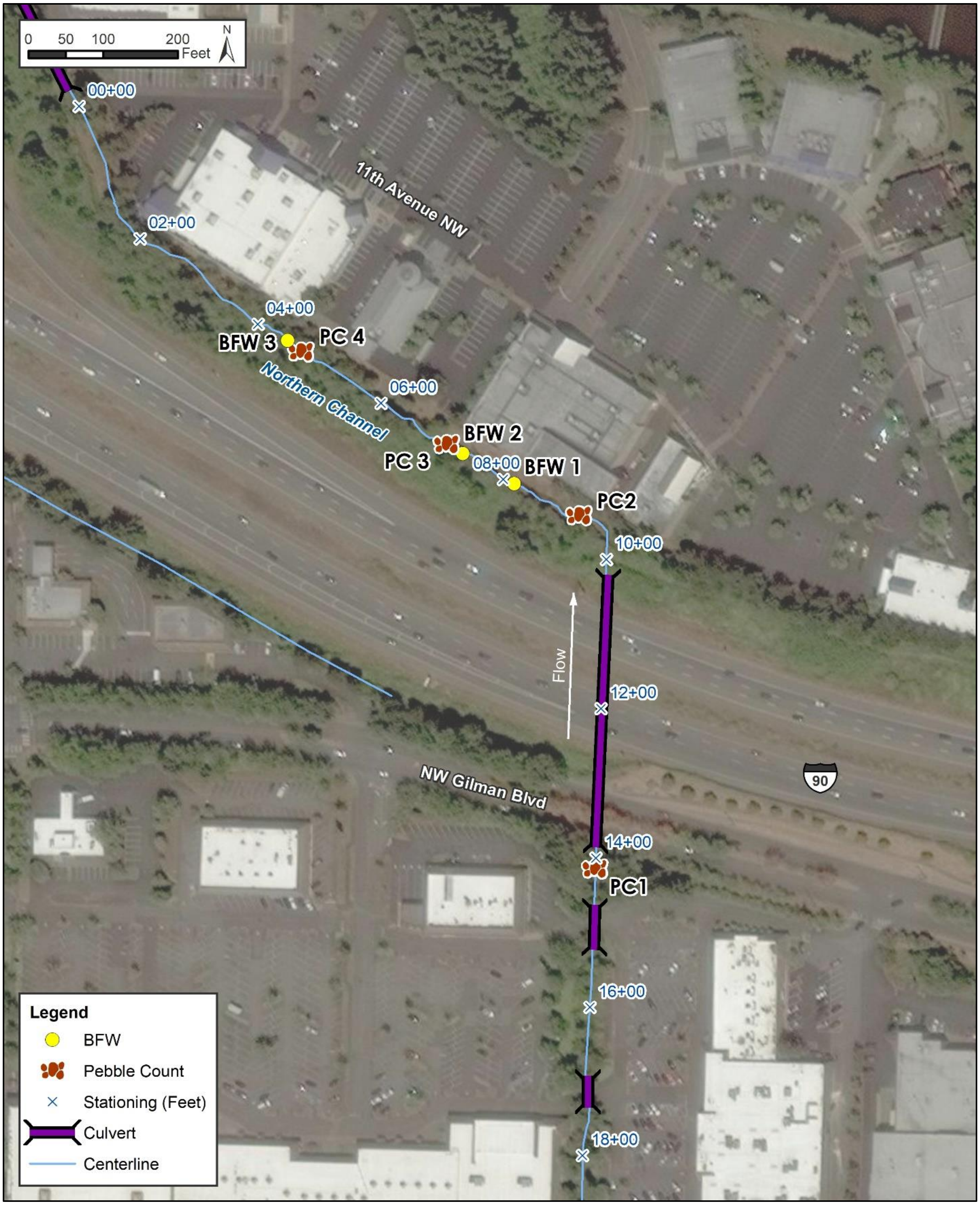

Figure 26: BFW and Pebble Count locations

Table 2: Bankfull width measurements

BFW #	Width (ft)	Included in Design Average	Location Measured	Concurrence Notes
1	8.0	Yes	Station 08+00	Concurrence not yet achieved
2	9.0	Yes	Station 07+30	Concurrence not yet achieved
3	9.5	Yes	Station 04+50	Concurrence not yet achieved
Design Average	9.0			

Figure 27 shows the location of BFW #1 downstream of I-90. This transect is in the upstream-most extent of the LWM restoration zone where riparian vegetation is restricted to reed canary grass and blackberry. The engineered LWM that was present in the channel was forcing small lateral gravel bars and local scour. The measurement was taken in a channel bend above a small boulder and NHC measured a BFW of eight feet.

Figure 27: BFW #1 at Station 08+00 (blue arrow indicates flow direction)

The second BFW measurement was taken about 70 feet downstream of BFW 1 in a straight glide reach (Figure 28). Bank slopes remain vertical and channel geometry consistent. NHC measured a channel width of nine feet in this location.

Figure 28: BFW #2 at Station 07+30 (blue arrow indicates flow direction)

The third BFW measurement was taken in a log-weir-forced riffle in the more densely wooded riparian area of the reference reach located just downstream of the PetSmart building (Figure 29). The wood produces local scour on the bed and banks so that bank slopes are visibly shallower in this reach widening the channel. NHC measured BFW of 9.5 feet in this riffle.

Figure 29: BFW #3 measured at Station 04+50 (blue arrow indicates flow direction)

2.8.3 *Sediment*

NHC collected pebble counts at four locations to represent the reaches upstream and downstream of the I-90 crossing (labeled in Figure 26). Characteristic grain sizes from the four pebble counts, PC 1 through PC 4, are summarized in Table 3 and Figure 30.

Table 3: Sediment properties upstream and downstream of project crossing

	Upstream Diameter (in) Station 14+15	Downstream Diameter (in) Station 09+15	Downstream Diameter (in) Station 07+05	Downstream Diameter (in) Station 04+45	Average Diameter (in)
D_{16}	0.3	0.2	0.5	0.3	0.4
D_{50}	0.7	0.5	1.1	0.9	0.8
D_{84}	1.1	0.9	1.4	1.2	1.2
D_{95}	1.3	1.2	1.8	1.6	1.5
D_{100}	1.8	1.8	5.0	5.0	3.4

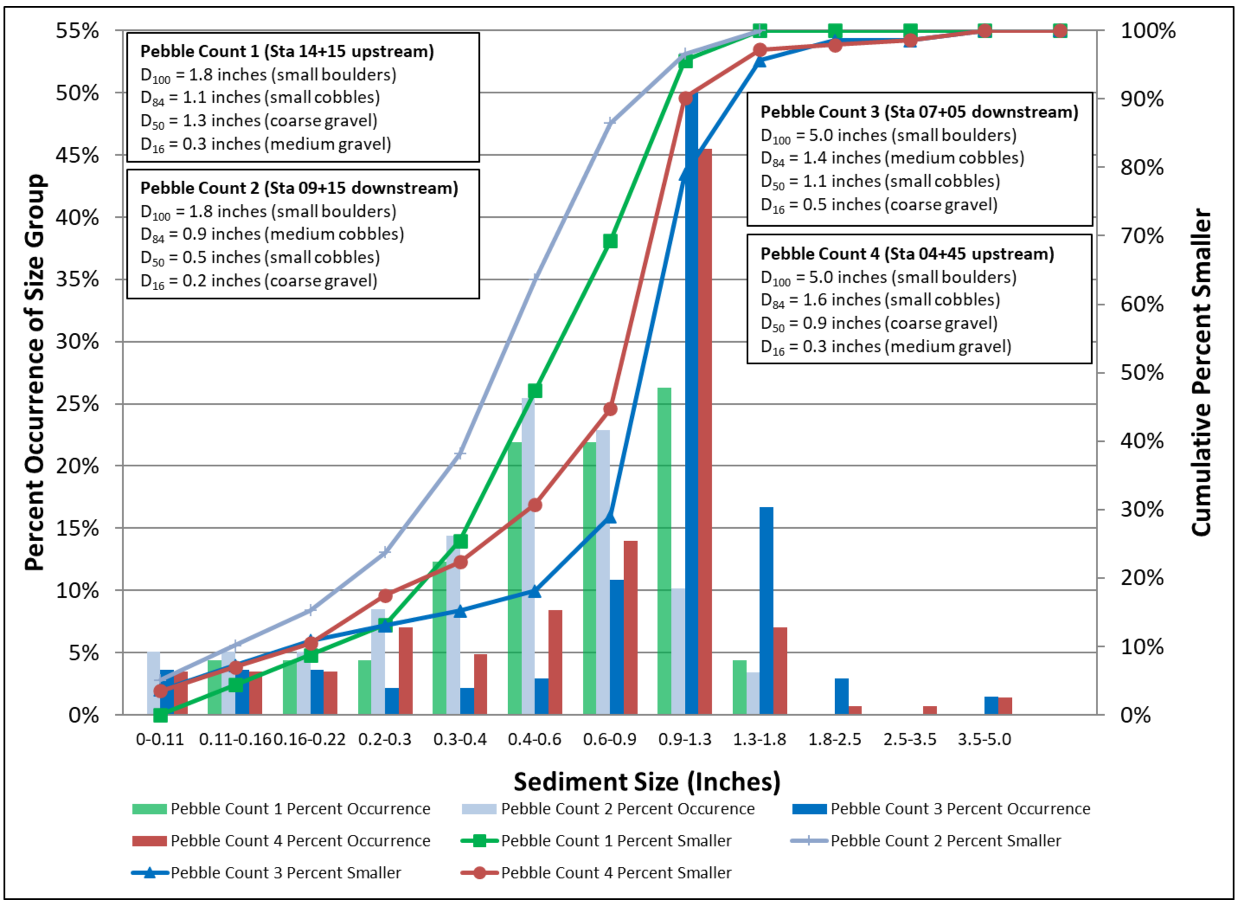

Figure 30: Particle size distribution for Unnamed Tributary to Tibbets Creek near I-90 MP 16.21

Most of the observable bed along the surveyed route was clay and fine sands or silt unless in areas of wood-forced riffle deposits, the frequency of which increases downstream of I-90 in the partially restored reach. NHC performed Wolman pebble counts on one riffle bed upstream of the crossing and three riffle-glide beds downstream to understand sediment transport efficiency throughout the reach. The first pebble count (PC 1) was taken 25 feet upstream of the I-90 culvert inlet in a 10-ft long riffle deposit. This sandy gravel deposit is a representation of the natural sediment supply available to the reach downstream of I-90 (Figure 31).

Figure 31: View of sandy gravel substrate at PC 1 Station 14+15

Downstream of the I-90 crossing, instances of wood-forced riffles increase as LWM becomes more abundant. Pebble Count 2 represents the bed surface of the first riffle observed downstream of I-90 at the upstream-most extent of the partially restored zone where channel width remains narrow and grass encroaches the channel bed (Figure 32).

Figure 32: View looking upstream at PC 2 Station 09+15 in narrow riffle

Pebble Count 3 was taken 315 feet downstream of the crossing in the reference reach in a wood-forced riffle bed. PC 3 was measured in the reference reach where the stream exhibits increased meandering and increased sediment storage in small lateral bars and behind channel logs. These riffle beds contain coarse gravel and small cobble that armor sand and fine gravel, all of which are pictured in Figure 33.

Figure 33: View looking at the riffle bed deposit of PC 3 at Station 07+05

Pebble Count 4 was measured 500 feet downstream of the I-90 crossing in a riffle deposit formed by an engineered notched log weir. The channel corridor maintains a dense canopy of mature trees in this segment of the reference reach, which supplies the channel with additional natural wood (Figure 33).

Figure 34: View looking at riffle bed deposit of PC 4 (Station 04+45)

Characteristic grain sizes from the four pebble counts, PC 1 through PC 4, are summarized in Table 3. Overall, the grain size distribution for PC 3 and 4 is more similar and slightly coarser than PC 1 and PC 2. The median diameter (D_{50}) for the PC 1 and 2 corresponds to medium gravel, slightly coarser for PC 3 and 4. The D_{84} of PC 3 and PC 4 is coarser as well with a maximum observed grain size of small cobble. The maximum observed grain size of PC 1 and PC 2 is coarse gravel. While the plans of the 12th Avenue restoration project are unknown, NHC interprets that the sediment of PC 3 and PC 4 was placed during construction due to the overwhelming presence of grains 0.9-1.3 inches and small cobble unique to these deposits. Naturally occurring boulders between 12 and 24 inches were occasionally observed during the site visit. Design boulders were observed within the reach with prior restoration, and angular boulders were observed in several locations.

2.8.4 *Vertical Channel Stability*

Water surface slopes in the vicinity of I-90 MP 16.21 remain consistent around 0.45 percent with some deviation from that slope in areas of culvert influence and channel confinement. The relevant slopes upstream and downstream of I-90 are labeled in the longitudinal profile of Figure 35, as well as the equilibrium slope and reference reach extents. The equilibrium slope (0.45 percent) was determined by comparing the water surface slope upstream and downstream of the I-90 crossing with the observed conditions in the field. Although the stream is continuing to respond to human manipulations from channelization and urbanization, evidence of notable channel degradation or aggradation was not observed in the crossing vicinity. Therefore, the current slope upstream and downstream of the crossing of 0.4 to 0.5 percent is the expected equilibrium slope of the stream. Slightly shallower slopes downstream are indicative of a wider channel corridor and increased channel sinuosity, whereas the highly confined and straight upstream channel maintains slopes at or above 0.45 percent. Immediately downstream of the I-90 culvert, channel slopes are shallower (0.15 percent) for 100 feet in an area that is affected by culvert outfall sedimentation due to a slope break from the steep 0.55 percent culvert.

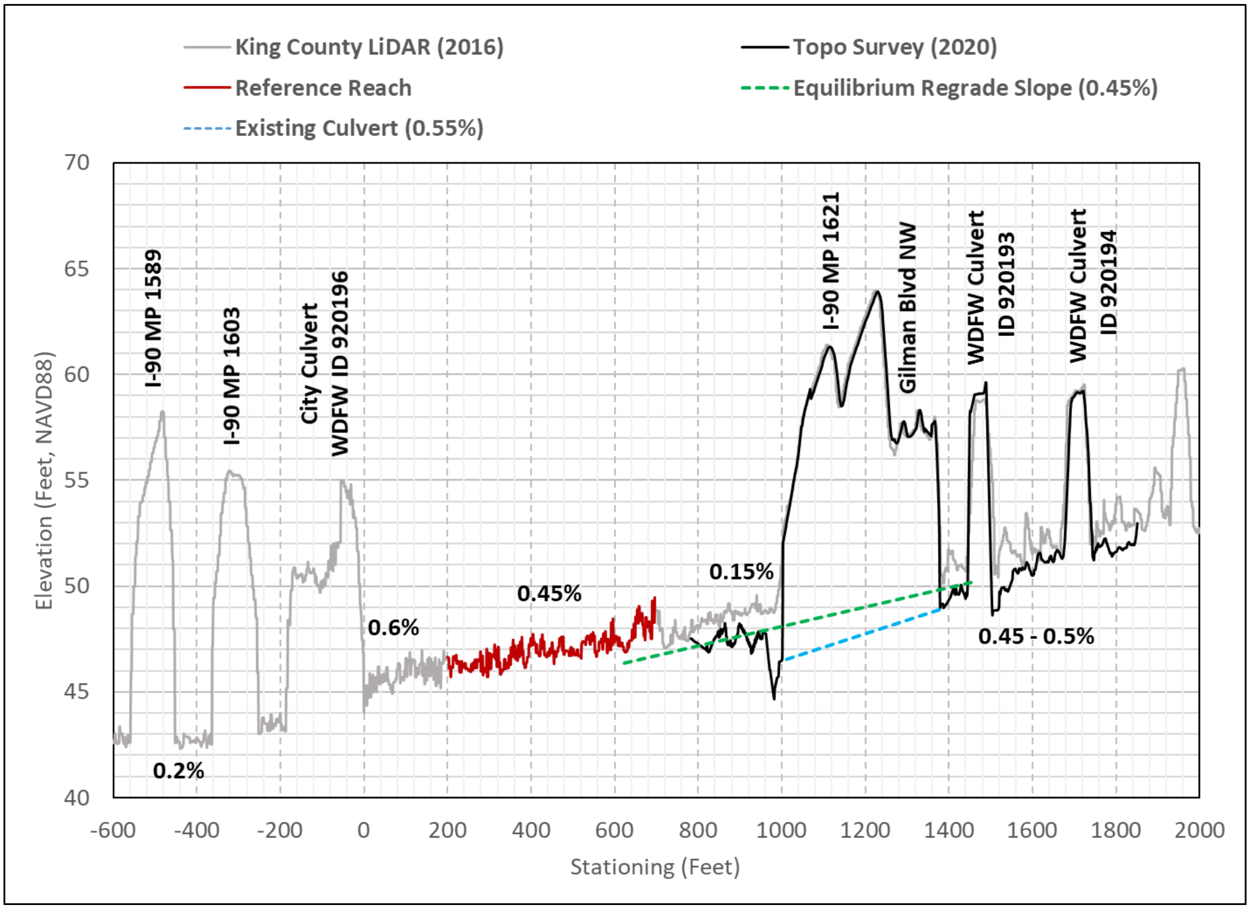

Figure 35: Longitudinal profile of northern Unnamed Tributary to Tibbets Creek near I-90

Channel conditions change downstream of the city culvert, WDFW Culvert 920196, labeled as Station 00+00 in Figure 35. A grade break occurs immediately downstream of the city culvert, where the stream transitions from a narrow 0.6 percent slope to a wider slackwater channel at less than 0.3 percent. The channel maintains an average slope of 0.2 percent downstream of the city culvert until its confluence with Tibbetts Creek main channel about 2,500 feet downstream. It should be noted that the city culvert is currently acting as grade control that can trigger an upstream regrade if replaced. A more natural longitudinal profile could be achieved if the 12th Ave reach was connected to the reach upstream of MP 16.03 along the current high flow diversion channel route. This would allow a smooth transition in slope that sustains instead of restricts energy on the bed in the downstream reach, which is currently aggrading and invaded by reed canary grass.

The unnamed tributary in the vicinity of I-90 is responding to a series of channel manipulations such as channelization, urbanization, and invasive vegetation. Stream channelization and urbanization have altered its natural sediment supply by disconnecting the stream from the floodplain area and replacing natural runoff with stormwater inflows along the reach. Local supply is limited to the bed and banks of the stream, which consist of mostly clay and some sandy gravel alluvium stored upstream of LWM. Upon close inspection of the size distribution and shape of the material, it appears that most of the streambed sediment downstream of I-90 was placed during the 12th Avenue restoration project and is not naturally transported from upstream.

The key grade controlling features observed along the reach are LWM, most of which have been engineered into the streambed and banks below the I-90 crossing. The only notable LWM observed above I-90 is the reach between WDFW culvert 920193 and the project culvert inlet where natural recruitment of wood from the dense canopy is possible. Downstream of I-90, anchored wood is common mostly on the banks with some submerged logs and log weirs present. Gravel accumulations were observed upstream of LWM. NHC interpreted the coarse gravel and small cobble deposits as channel bed armoring, currently protecting an underlying layer of finer gravel and sand alluvium that overly the local clay base. Local scour pools between one and two feet deep were observed in areas of instream LWM.

Figure 36: View of submerged LWM initiating gravel storage in small lateral bars and riffle-glide morphology (blue arrow indicates flow direction, white arrow points to submerged LWM) (Sta. 08+10)

Removal of the existing I-90 culvert is not expected to trigger a regrade of the channel upstream. Under existing conditions, the culvert is not providing grade control to the reach above I-90. In addition, naturally recruited LWM currently provides natural grade control to the upstream reach in the form of sediment storage. Incision is possible downstream if the armor layer is eroded during high flows and the coarse material is not replaced to the reach, exposing sandy gravel and the underlying clay. This is the likely outcome in the rare event of a 100-year Issaquah Creek overflow event, where the corridor would accommodate 600 cfs streamflow. However, given the low probability of such an event occurring, the streambed should not be engineered to this flow but to normal flows. If the channel were to regrade to a lower slope, around 0.3 percent, the channel could degrade 0.5 feet at the channel crossing. The largest LWM jam observed in the field about 60 feet upstream of the project culvert inlet was storing about 0.5 feet of sediment and debris upstream. Given the compromised sediment supply upstream, aggradation of more than one foot is not likely within or upstream of the I-90 crossing. Aggradation is more likely downstream of the I-90 crossing in the reference reach area where LWM is more abundant. Beavers were observed 2,000 feet downstream of this crossing at the I-90 MP 15.82 crossing location. Aggradation of two feet was observed in a beaver dam here.

2.8.5 *Channel Migration*

The northern Unnamed Tributary to Tibbetts Creek is not at risk of channel migration or floodplain expansion in the vicinity of I-90. Under existing conditions, the upstream channel is confined within vegetated steep overbank slopes strictly limiting the potential for migration (Figure 37). There were no observable instances of bank erosion or bank failure upstream of I-90 and the channel was mostly straight. Invasive reed canary grass and ivy colonization of the channel banks and corridor currently constrains the thalweg to a fixed position. The existing floodplain is 60 feet wide, bound on either side by commercial area parking lots, and is not expected to expand in the future.

Figure 37: View of existing floodplain conditions upstream of I-90 (blue arrow indicates flow direction) (Sta. 34+70)

Downstream of I-90, the floodplain widens to 100 feet in width, laterally constrained by I-90 westbound on the left bank and commercial shopping stores on the right bank (Figure 38). The floodplain can therefore not expand. The channel exhibits greater sinuosity downstream of the crossing within a grassy channel bench. NHC measured sinuosity in the field of 1.1, defined as the length of the channel divided by the length of the flow corridor. The channel is expected to maintain sinuosity in the partially restored reach that contains LWM. This restored reach is expected to maintain active bank scouring and widening but remain constrained between the present infrastructural barriers. In the event of a large flood, such as 100-year overflow from Issaquah Creek, the channel is expected to migrate within the bounds of the channel bench. However, channel migration is not expected under normal flow conditions as bank strength remains high.

Figure 38: View of narrow floodplain corridor downstream of I-90 with Big Lots and other commercial stores on the right bank and I-90 west-bound behind the blackberry shrubs on the left bank (blue arrow indicates flow direction)

2.8.6 *Riparian Conditions, Large Wood, Other Habitat Features*

There is varied potential for large wood recruitment within the immediate vicinity upstream and downstream of I-90. The existing riparian corridor between WDFW Culvert ID: 920193 and the I-90 culvert inlet contains mostly invasive English ivy and a few mature cottonwoods (Figure 39). There were a few small pieces of wood in the stream (DBH one foot or less) influencing channel hydraulics by forming small log jams and scour pools (Figure 22). The mature trees provide ample shading in this short reach. There are fewer trees upstream of WDFW Culvert ID: 920193. Both banks have been colonized by reed canary grass upstream of this point and the stream therefore lacks the same degree of canopy shading.

Figure 39: Riparian conditions upstream of the I-90 crossing between Station 14+50 and 14+00 (arrow indicates flow direction)

Immediately downstream of I-90, the dominant riparian vegetation on the channel bench is reed canary grass (Figure 40). There is limited shade and large wood recruitment potential in this reach. The riparian corridor transitions from mostly grass to increasing mature tree canopy starting 200 feet downstream of the I-90 culvert outlet. Downstream of this transition, the stream is shaded by mostly alder and cottonwood trees on the banks and channel bench, supplying natural LWM to the channel. The reference reach contains a mix of trees, grass, and shrubs including some Himalayan blackberry and fern.

Figure 40: Riparian conditions downstream of I-90 showing the transition from reed canary grass to more dense woody trees further downstream (blue arrow indicates flow direction) (Sta. 07+50)

Instances of in-channel LWM increase downstream of I-90 as a result of past restoration projects in the reach. Engineered LWM was observed anchored into channel banks, in toe structures, and spanning the width of the channel to create notched log weir structures. The average DBH of the engineered wood is 1.5 feet and only one piece of large wood was used to create each wood feature in this restored zone. To target Kokanee habitat rehabilitation, the project avoided multi-piece racked designs that create deeper pools that attract predatory smallmouth bass (Monahan, personal comm. 2020). Greater channel complexity was observed downstream in the partially restored section of the stream than upstream of the crossing, especially in the more dense canopy area (Figure 41). Sand and gravel accumulate upstream of the log weirs adding hydraulic roughness to the channel in the form of riffle bed structures. Downstream pools have formed ranging from 1 to 1.5 feet in tail-out depth. The LWM is therefore acting as grade control downstream of I-90.

Figure 41: View of riparian corridor in the reference reach showing notched log weir structures and natural wood recruitment (blue arrow indicates flow direction) (Sta. 03+16)

3 Hydrology and Peak Flow Estimates

There are no published historic or current streamflow gages located on the Unnamed Tributary to Tibbetts Creek; therefore, streamflow statistics for the tributary ditch cannot be directly calculated. Additionally, due to the highly urbanized nature of the watershed, the Region 3 USGS Regression equations (Mastin et al., 2016) were not applicable for determining the peak flows for the design of the proposed crossings at I-90 MP 16.21.

An HSPF model of the Tibbetts Creek watershed was used for hydrologic analysis. The model was originally created as part of a Lake Sammamish/Lake Washington basin modeling effort in the early 1990s. It was most recently updated and recalibrated (for Issaquah Creek) in 2019 (King County, 2019). The model was run without modification to subbasin or routing elements, and results were then scaled based on the drainage area ratio between the model output point and the area contributing to the project crossing. A frequency analysis was performed on the HSPF results utilizing a Log Pearson Type III distribution following Bulletin 17C methodology. The frequency analysis used weighted skew employing regional skew coefficients published in SIR 2016-5118 (Mastin et al., 2016). Peak flow results from the hydrologic analysis are provided in Table 4. 2080 Predicted 100-year flows were calculated by scaling the 100-year flow by a basin-specific factor provided by WSDOT, discussed further in Section 7.2.

Table 4: Peak flows for Unnamed Tributary to Tibbetts Creek at I-90 MP 16.21

Mean Recurrence Interval (MRI)	HSPF Analysis Peak Flow (cfs)
2	**38**
10	**54**
25	**62**
50	**68**
100	**73**
500	**85**
2080 Predicted 100	**100**

Apart from peak flows generated from within subbasins, crossings in this vicinity are impacted by overflow from Issaquah Creek. Revision 7 of the King County, Washington and Incorporated Areas Flood Insurance Study (FIS) (FEMA, 2010) included a detailed study of lower Issaquah Creek and identified an overflow path along Gilman Boulevard from Issaquah Creek (called the Gilman Boulevard Overflow). The overflow pathway is activated between the 10- and 50-year recurrence interval and exits Issaquah Creek upstream of I-90, flowing overland at Sena Park and through a designated ditch to the west. The limit of the detailed study ended just upstream of the I-90 MP 16.21 crossing, which is the same ditch that flows through the I-90 MP 16.03, 15.82, and 15.89 crossings. The overflow also has potential to continue overland to the I-90 MP 15.92 and I-90 EB Ramp MP 15.92 crossing, though this area was not included in the detailed study (Figure 42). Overflow from Issaquah Creek and the Unnamed Tributary to Tibbetts Creek are assumed to not be coincident, due to the significant difference in contributing basin area.

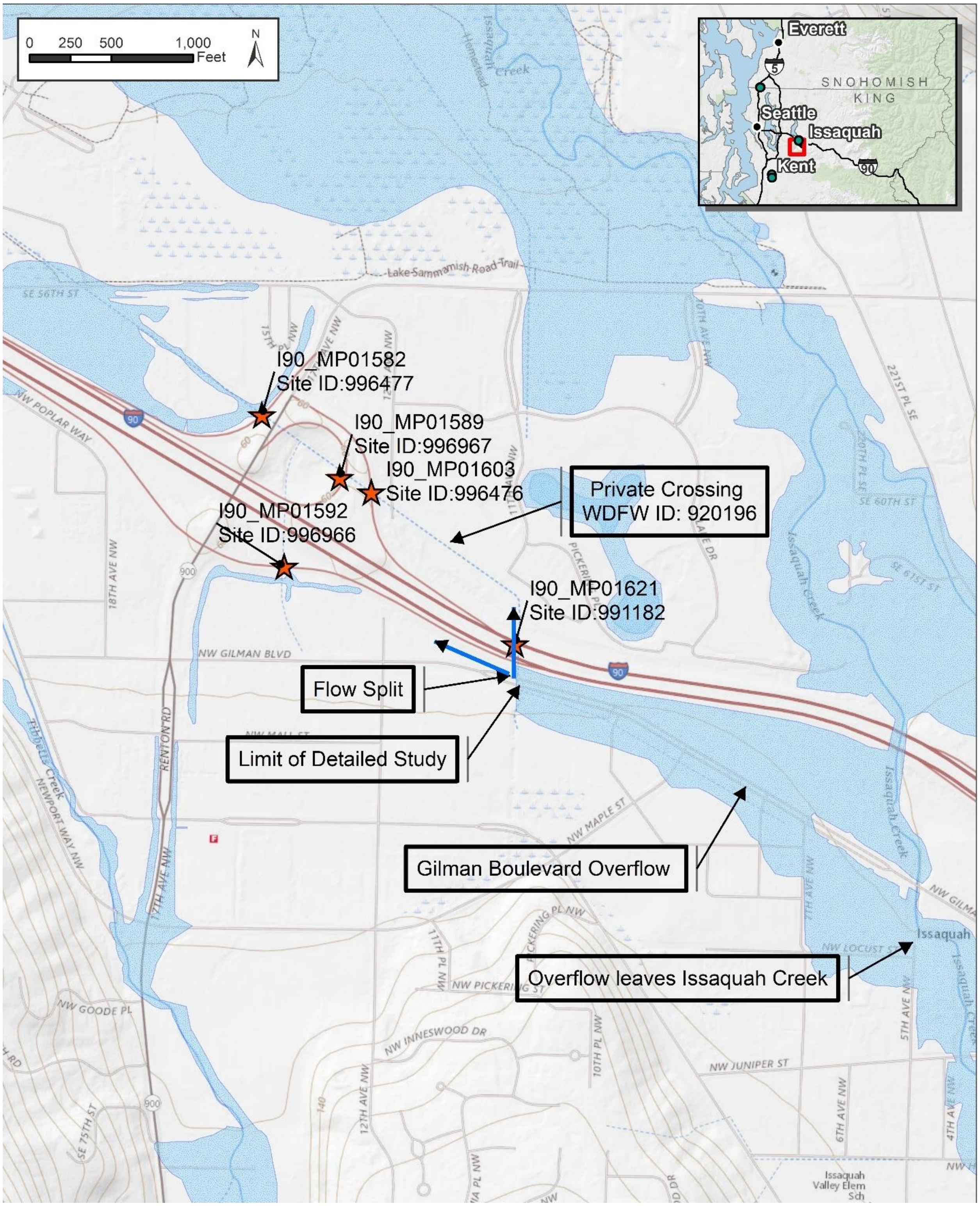

Figure 42: Gilman Boulevard Overflow overview map

Table 5: Gilman Boulevard Overflow peak discharge (FEMA, 2010)

Mean Recurrence Interval (MRI)	Overflow Peak Discharge (cfs)
10	**0**
50	**370**
100	**610**
500	**1,250**

Since the Issaquah Creek overflow scenario is several times greater in magnitude than the computed HSPF design flows, it would increase the designed hydraulic opening, potentially quite significantly. Additionally, there is a lack of information regarding how the overflow was determined and how it would interact with the infrastructure upstream. Therefore, a conversation was had with WSDOT to determine which flows should be used for design. It was determined that the natural hydrology of the basin represented by the HSPF modeling would be used to determine bankfull widths and guide channel design. However, the more conservative Issaquah Creek flows would be used for sizing the crossing structures.

Following this decision, a regional SRH-2D model was created that mapped the overflow paths in the 100- and 500-year events along Gilman Boulevard and to the northern and southern channels of Unnamed Tributary to Tibbetts Creek. The model provided estimates for the flow split between the two channels to be used for crossing design.

In the existing condition, the I-90 crossing at MP 16.21 does not have the capacity to carry the full 100- and 500-year flows, and the majority of flow bypasses the culvert into the southern channel that crosses I-90 further to the west at MP 15.92. Since the order of replacements for the I-90 and SR 900 interchange culverts is yet to be determined, the MP 15.92 crossings will be designed to accommodate the existing flows coming into the southern channel as overflow from Issaquah Creek.

The proposed condition flows were determined based on modeling the proposed grading at MP 16.21 (which was based on local runoff) to determine how much of the overflow the proposed MP 16.21 channel would convey. It was determined that most of the Issaquah Creek overflow in the 100- and 500-year events will be contained within the proposed MP 16.21 channel; consequently, the crossing structures at MP 16.21, MP 16.03, and MP 15.89 will be designed to accommodate the portion of the Issaquah Creek overflow that the modeling indicates would pass the MP 16.21 proposed channel. As stated above, the I-90 crossing at MP 15.92, located further west in the southern channel of Unnamed Tributary to Tibbetts Creek, will be designed for the existing overflow split, since the order of culvert replacement is unknown. There may be opportunity in the future to downsize either the MP 16.21 crossing or the MP 15.92 crossing once order of construction is known, since they both don't need to be sized for the majority of the Issaquah Creek overflow. The crossing at MP 15.82 will be designed to accommodate the full 610 cfs of overflow since it is downstream of the confluence between the northern and southern channels of the Unnamed Tributary to Tibbetts Creek.

Table 6: Existing and proposed design flow distribution

Crossing ID	Existing Overflow Peak Discharge at Structure (cfs)	Proposed Overflow Peak Discharge at Structure (cfs)	Design Peak Discharge at Structure (cfs)
MP 16.21	110	600	600
MP 16.03	110	600	600
MP 15.92	500	10	500
MP 15.89	110	600	600
MP 15.82	610	610	610

4 Hydraulic Analysis and Design

The hydraulic analysis of the existing and proposed I-90 Unnamed Tributary to Tibbetts Creek crossing was performed using the U.S. Bureau of Reclamation's SRH-2D Version 3.2.4 (USBR, 2017) computer program, a two-dimensional hydraulic and sediment transport numerical model. Pre- and post-processing for this model was completed using SMS Version 13.0.12 (Aquaveo, 2018).

Two scenarios were analyzed for determining stream characteristics for Unnamed Tributary to Tibbetts Creek with the SRH-2D models: 1) existing conditions with the 4-foot diameter, 376-foot-long culvert and 2) future conditions with the proposed 17-foot minimum hydraulic opening.

4.1 Model Development

4.1.1 *Topographic and Bathymetric Data*

The channel geometry data in the model was obtained from the MicroStation and InRoads files supplied by the WSDOT, which were developed from topographic surveys performed by WSDOT. The survey data was supplemented with 2016 LiDAR data (OCM Partners, 2020) with 3-foot grid spacing. Proposed channel geometry was developed from the proposed grading surface created by using SMS. All survey and LiDAR information are referenced against the NAVD88 vertical datum.

4.1.2 *Model Extent and Computational Mesh*

The model extends from 60 feet upstream of the I-90 MP 16.21 crossing inlet to approximately 250 feet downstream of the crossing outlet covering a channel length of 675 feet. The upstream end of the model was truncated downstream of the private culvert upstream of I-90 MP 16.21 because the higher flow values backwater above this culvert, and overflow typically enters the culvert though overland flow and through the ditch system to the east. The width of the model was determined to give adequate space for flow to spread into developed flow paths, but then exit boundary conditions were utilized to quantify flow leaving the system. In particular, the exit pathway to the west along Gilman Boulevard allows flow to be quantified as it proceeds out of the system. Downstream of the crossing, there is a ditch that enters from the east. Since there is a berm upstream of this channel, no flow is allowed to exit the model at this location, simulating a backwater condition. The extents of the existing and proposed model domains were set sufficiently far enough away from the I-90 crossing to minimize any effects on the project site hydraulics and to enclose all areas that were expected to be inundated for the simulated flows. Based on channel and floodplain topography, the meshes were created with an element density that represents the topographic survey and consist of approximately 23,325 elements for existing conditions and 44,624 elements for proposed conditions. For both existing and proposed conditions, the elements throughout the floodplain and near the upstream and downstream domain limits have an approximate 5- to 10-foot vertex spacing. To adequately represent the existing channel shape near the culvert's inlet and outlet, a 1- to 3-foot vertex spacing was utilized. For the proposed conditions mesh, 1- to 3-foot vertex spacing was utilized through the crossing. The mesh transitions gradually between these element resolutions to ensure a stable model.

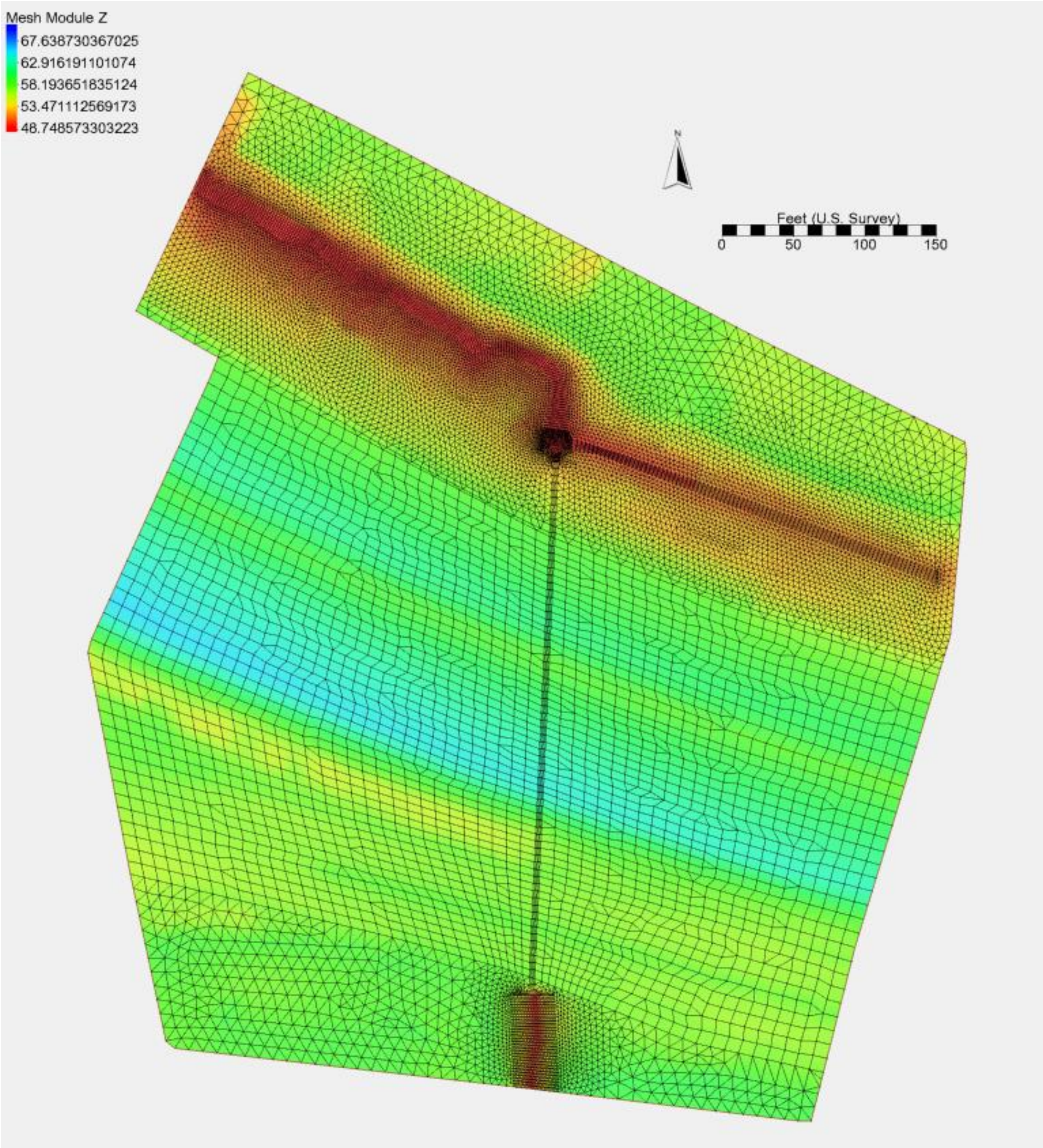

Figure 43: Existing conditions computational mesh with underlying terrain

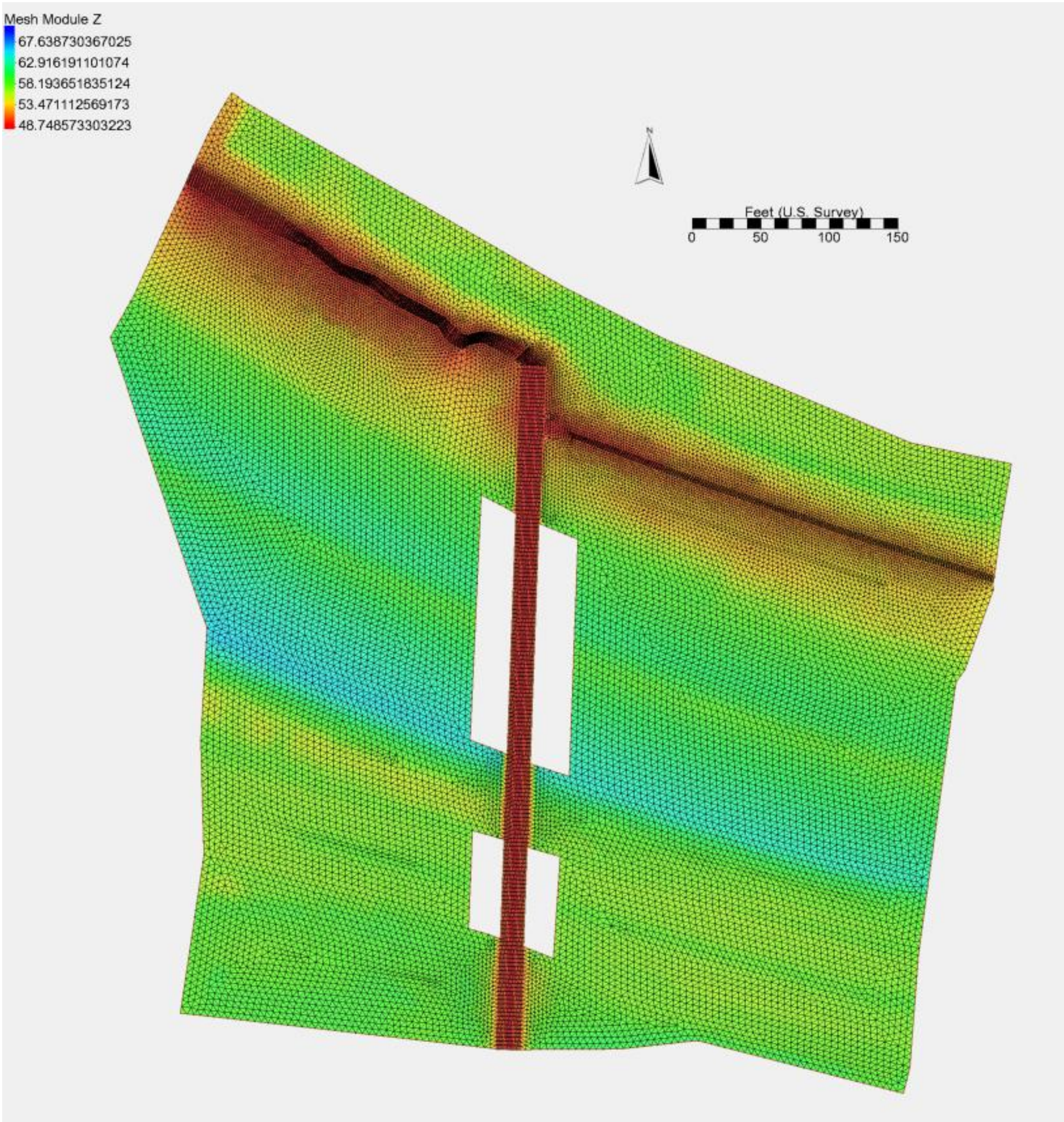

Figure 44: Proposed conditions computational mesh with underlying terrain

4.1.3 *Materials/Roughness*

The United States Forest Service Flow Resistance Coefficient Selection in Natural Channels: A Spreadsheet Tool (Version 2) (Yochum, 2018) was used to compute roughness for the stream channel based on applicable parameters. Floodplain roughness was determined by visual estimation and comparison (Arcement and Schneider, 1989). Existing LWM in the immediate vicinity of the culvert was incorporated explicitly in the model because of the possibility to cause localized flow deflection and complex hydraulics. LWM was modeled as an obstructed area also with higher roughness values, based on the diameter, elevation, and length noted in the WSDOT survey. A drag coefficient of 1.2 and a roughness of 0.2 were assumed for all logs. Though channel complexity features are proposed inside of the crossing, the relative channel obstruction is less than reaches with LWM installation.

Table 7: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Land Cover Type	Manning's n
Pavement	0.013
Grass	0.03
Building	0.20
Existing Overbank	0.065
Existing Channel	0.035
Proposed Channel – No LWM	0.035
Proposed Channel – With LWM	0.055

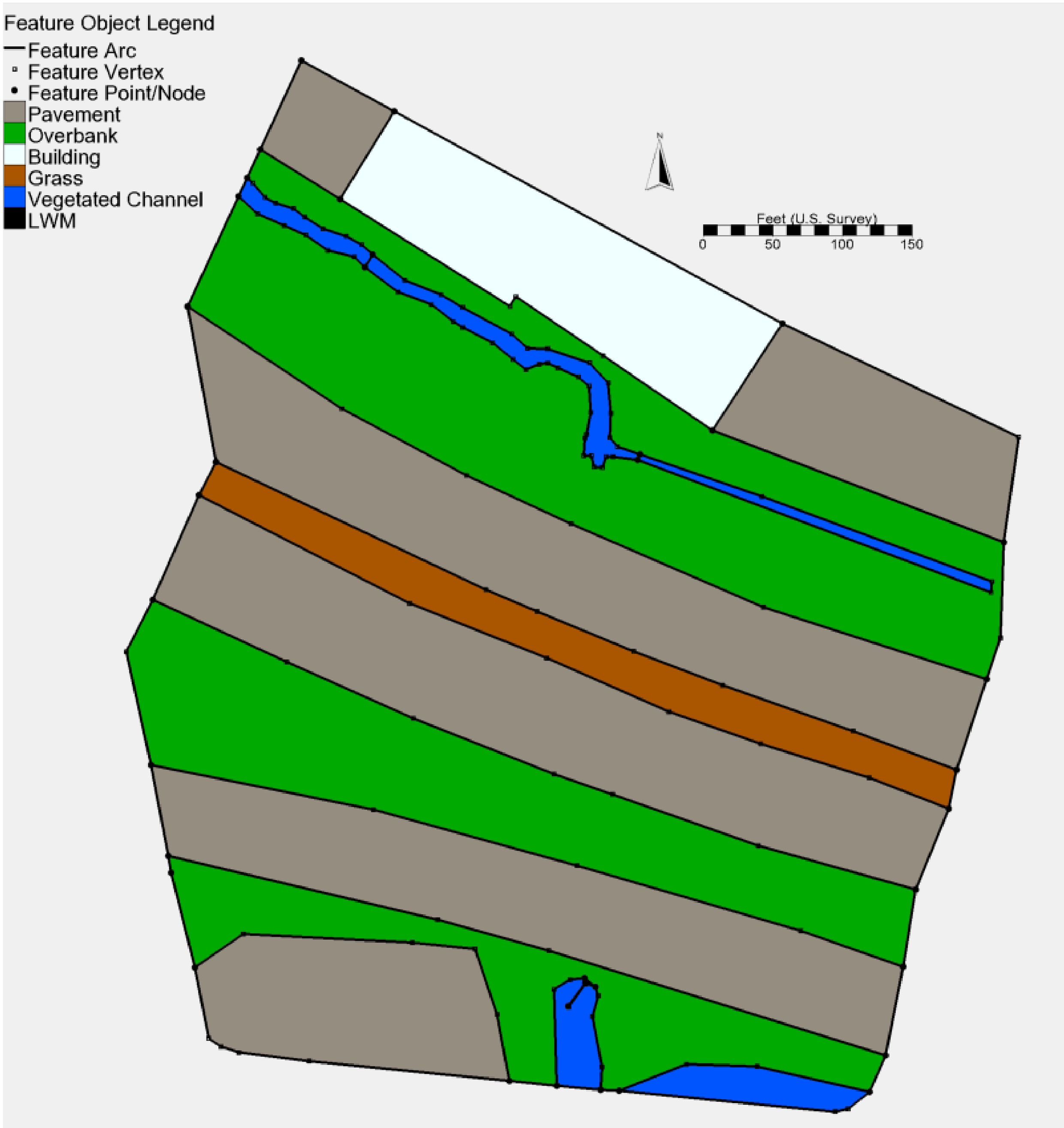

Figure 45: Spatial distribution of roughness values in the existing condition SRH-2D model

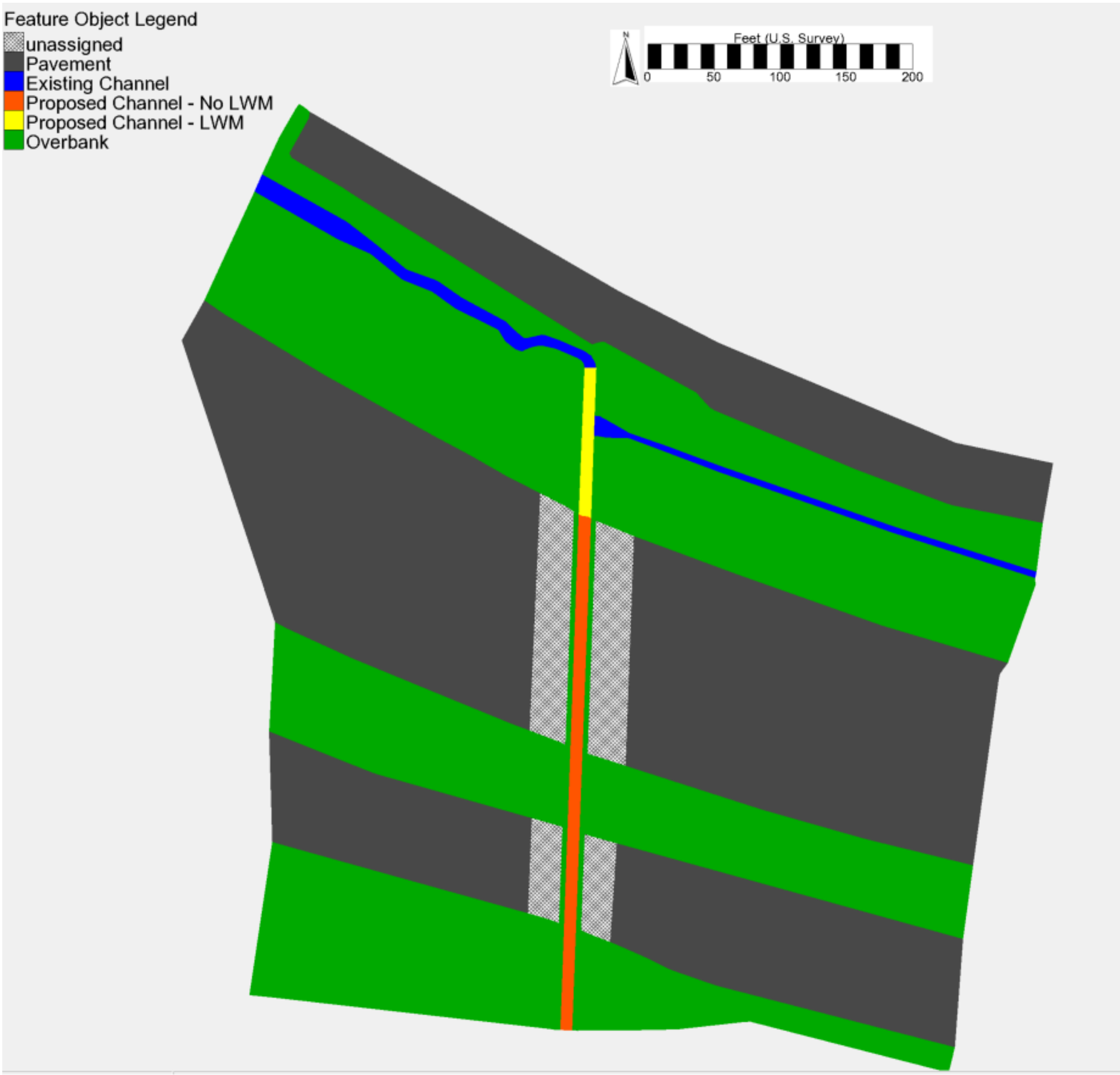

Figure 46: Spatial distribution of roughness values in the proposed condition SRH-2D model

4.1.4 *Boundary Conditions*

The existing conditions model required the specification of three boundary conditions, while only two of these were required in the proposed conditions model. The two boundary conditions that were common in the existing and proposed conditions models were the inflow rate at the upstream end of the model domain and the water surface elevation (WSE) at its downstream end.

The inflow boundary was set as a constant inflow, with a flow rate corresponding to the peak flow being modeled. The inflow rates specified as the upstream boundary conditions, in both the existing and proposed conditions models, are provided in Table 4 (see Section 3 for determination of peak flows). The upstream boundary condition was placed far enough upstream of the project site to not influence the hydraulic results at the I-90 MP 16.21 crossing. The inflow for all peak flow simulations was designated subcritical to match the expected flow regimes on Unnamed Tributary to Tibbetts Creek at the boundary condition. The model was run in steady-state mode for all modeled simulations.

The downstream boundary condition for the existing and proposed conditions models consists of WSEs that corresponded to the normal depth at the downstream end of the domain for the simulated peak flow (Table 8). A sensitivity analysis on the downstream boundary condition was performed to ensure that the selected WSE did not result in a rapid drawdown or backwater of the water surface near the downstream mesh boundary. The sensitivity analysis also revealed that the hydraulics at the crossing were unaffected by the WSE selected as the downstream boundary condition. The four boundary conditions on the southwest domain edge of the model represent possible flow pathways during the Gilman Boulevard Overflow event.

Table 8: Summary of parameters for downstream boundary conditions

Boundary Condition	Energy Slope	Roughness
Downstream Outlet	0.031	0.0475
Ditch North of Gilman Blvd.	0.01	0.035
Along Gilman Blvd.	0.01	0.012
South of Gilman Blvd.	0.01	0.012
Building	Blocked	Blocked

The existing conditions model required the specification of one additional boundary condition for simulating the existing 4-foot diameter culvert. This additional boundary condition required the specification of a pair of arcs, which were located at the surveyed locations of the existing culvert inlet and outlet. This boundary condition enables SMS to interact with the Federal Highway Administration’s (FHWA) HY-8 culvert analysis software (FHWA, 2019) for calculating the hydraulics through the existing I-90 MP 16.21 culvert. The culvert geometry, culvert type, and site data obtained from the WSDOT survey and field visit were utilized for compiling an HY-8 file. This file was then associated with SRH-2D and used to compute the culvert hydraulics.

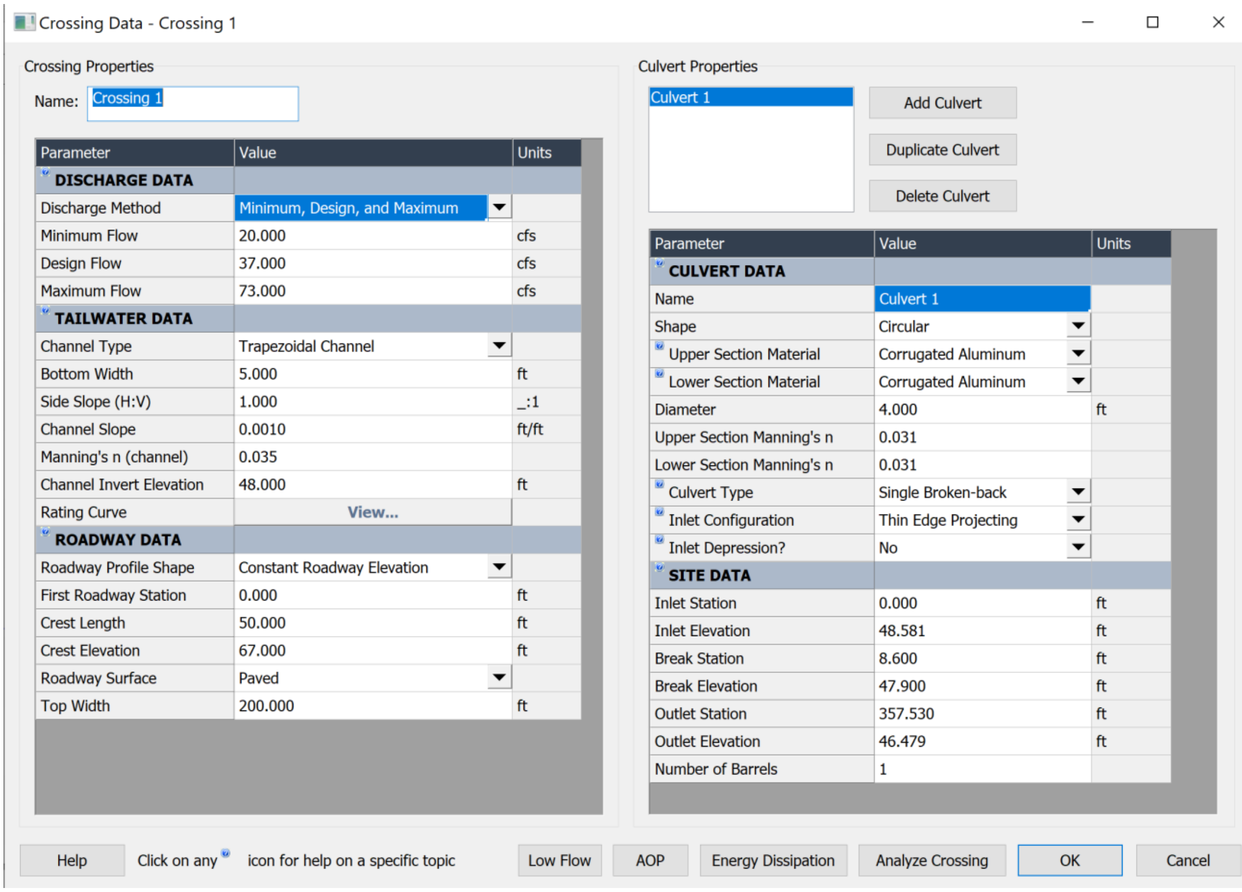

Figure 47: HY-8 culvert parameters

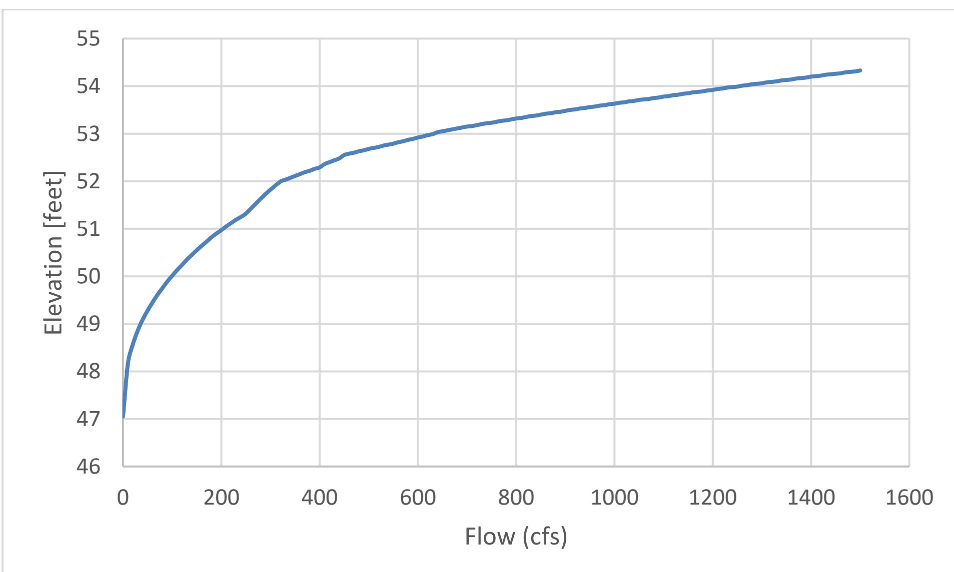

Figure 48: Downstream Unnamed Tributary to Tibbetts Creek normal depth rating curve

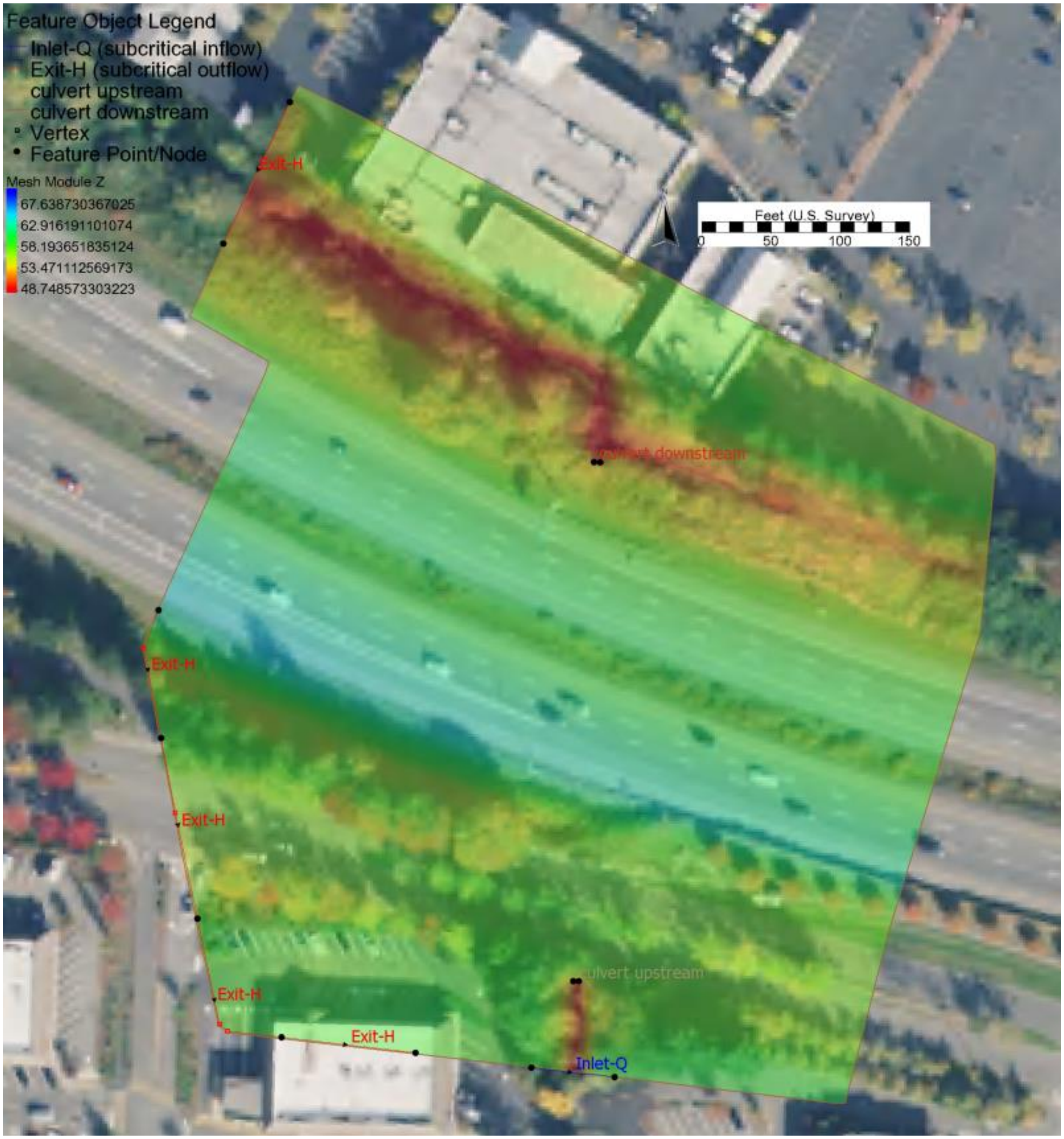

Figure 49: Location and type of boundary conditions

4.1.5 *Model Run Controls*

Model simulations were run until no change in water surface elevation was observed upstream and downstream of the crossing greater than 0.01 feet over the prior hour of simulation time. This typically resulted in the model being run from four to eight hours using a timestep of one second for the lower flows and up to 0.25 seconds for the high flow events.

4.1.6 *Model Assumptions and Limitations*

The model assumes that flow will enter the upstream boundary condition in a uniform condition; this assumption negates the potential impacts of the upstream culvert. This assumption is required to ensure that the design flow reaches the I-90 MP 16.21 crossing. The existing 4-foot diameter culvert that conveys the main flow path from the Issaquah Creek overflow was assumed to come into the system at this inflow location, although for existing conditions it enters at the culvert junction. The entry location for proposed conditions will be determined in a later phase.

4.2 Existing Conditions Model Results

The simulated 2-year water surface elevation tends to extend significantly into the bankfull bench, indicating that a 1.4- to 1.5-year recurrence interval (Castro et al. 2001) may be a more accurate representation of the bankfull flow (Figure 53). Stormwater input, upstream wetland area, and upstream culverts could also influence peak flow value and attenuation dynamics. The 2-year to 500-year recurrence interval flow is entirely conveyed through the crossing, with no flooding on Gilman Boulevard or I-90. However, for the 100- and 500-year recurrence interval flows, there is significant backwater upstream of the structure (Figure 52). All of the Gilman Boulevard Overflow scenarios (50- to 500-year) overtop Gilman Boulevard and send a portion of the flow to the northwest along Gilman Boulevard. However, I-90 is not overtopped during any simulation. The maximum modeled flow through the culvert is approximately 110 cfs in the existing condition; flows greater than this exit the mesh to the southwest along Gilman Boulevard. Since most of the overflow scenarios exceed the hydraulic capacity of the existing opening, a backwater condition exists upstream of the crossing. This results in relatively low velocities upstream of the culvert. However, the relatively steep slope of the crossing accelerates the flow existing the existing culvert, resulting in high velocities at the outlet. The scour hole downstream of the culvert outlet corroborates these simulation results. Downstream of the 90-degree bend, the flow becomes relatively more uniform, with velocities and shear stress conditions more similar to the reference reach simulations. The 2-year recurrence interval flow also reveals two constrictions in the downstream reach, near the 90-degree bend. One is caused partially by a rock pile along the right bank and the other is a riffle complex that backs up lower flows. The downstream constriction degree of impact decreases with increasing flow and is does not appear to exhibit significant control at the 100-year recurrence interval flow.

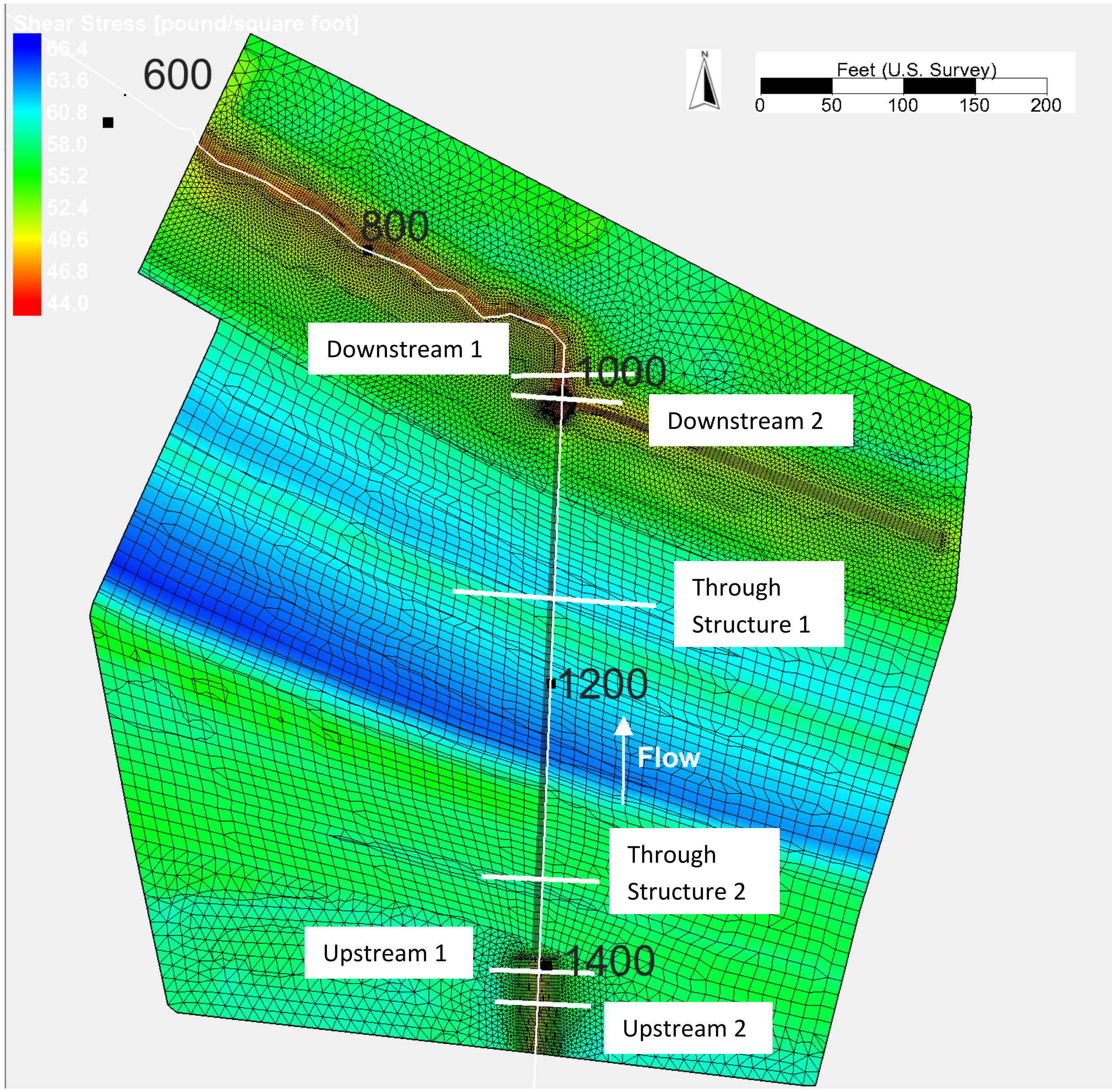

Figure 50: Locations of cross-sections used for results reporting

Figure 51: Longitudinal profile stationing for existing and proposed conditions

Table 9: Average hydraulic results for existing conditions (Upstream 2 and Downstream 1, Figure 50)

Event ($Years$)	WSE (ft)		Depth (ft)		Velocity ($\frac{ft}{s}$)		Shear ($\frac{lb}{ft^2}$)	
	US	*DS*	*US*	*DS*	*US*	*DS*	*US*	*DS*
2	52.03	50.33	1.43	1.82	1.63	0.64	0.20	0.02
100	53.65	51.03	2.12	1.83	1.25	0.79	0.12	0.03
500	54.11	51.23	2.39	1.92	1.21	0.83	0.11	0.04
100-year Overflow	60.22	51.44	5.04	2.02	1.64	0.87	0.31	0.04
500-year Overflow	61.22	51.47	6.05	2.3	2.64	1.73	0.74	0.04

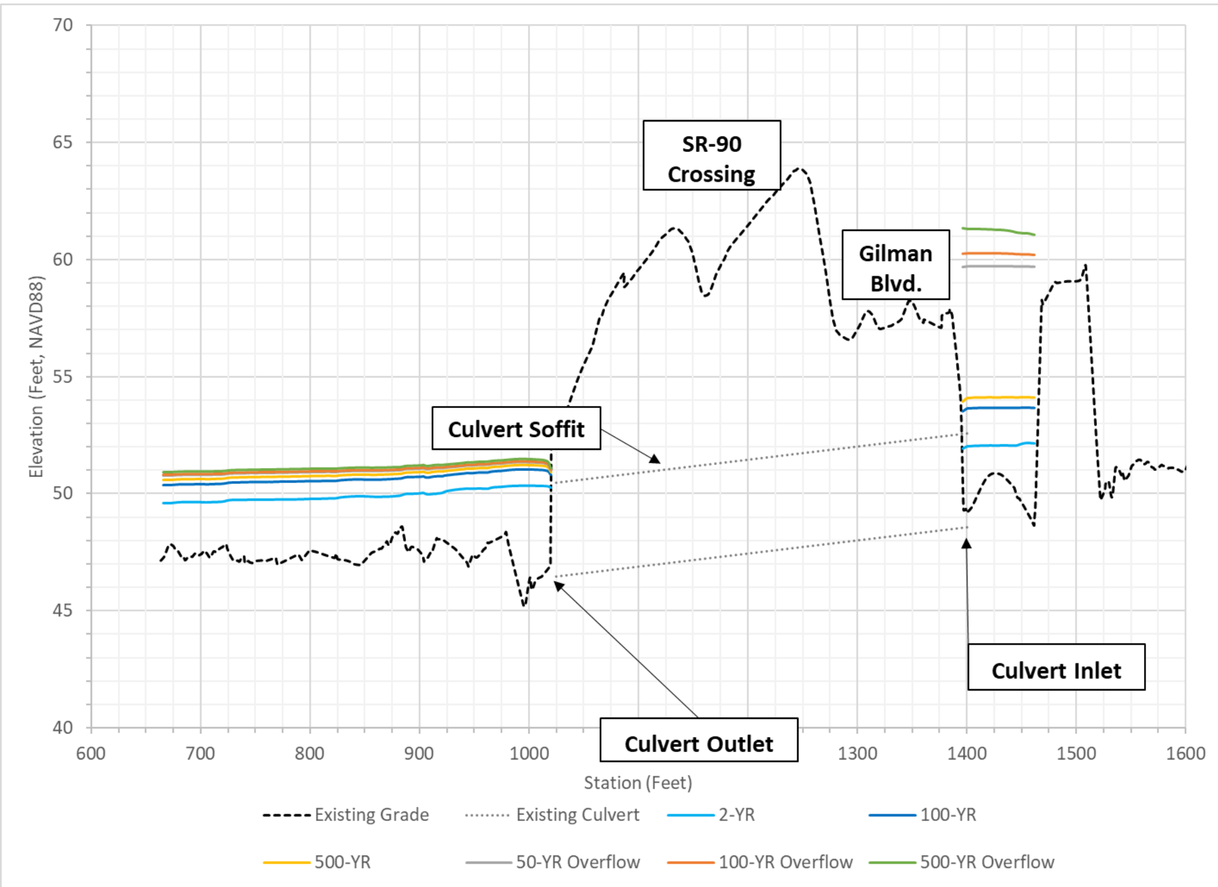

Figure 52: Existing conditions water surface profiles

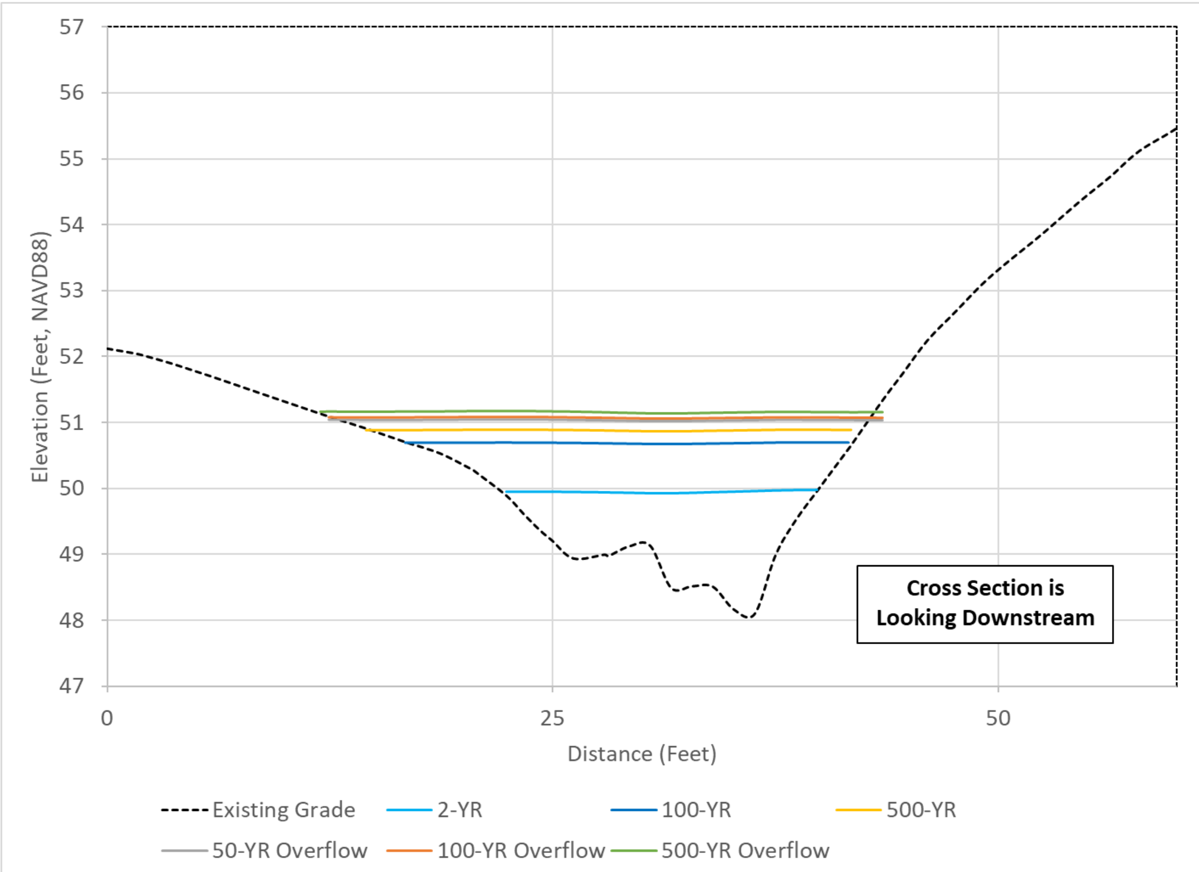

Figure 53: Typical downstream existing channel cross-section

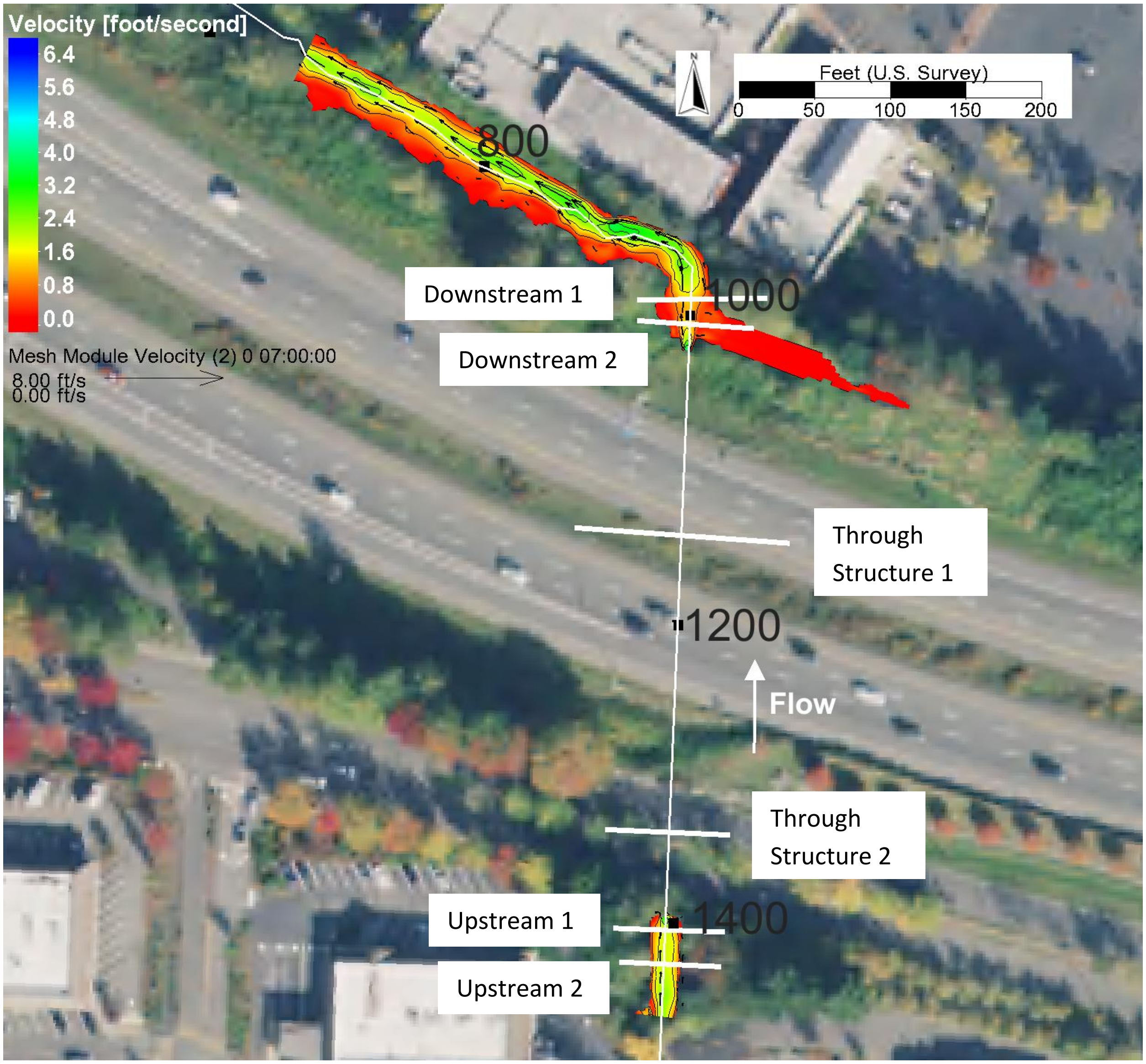

Figure 54: Existing conditions 100-year velocity map with cross-section locations

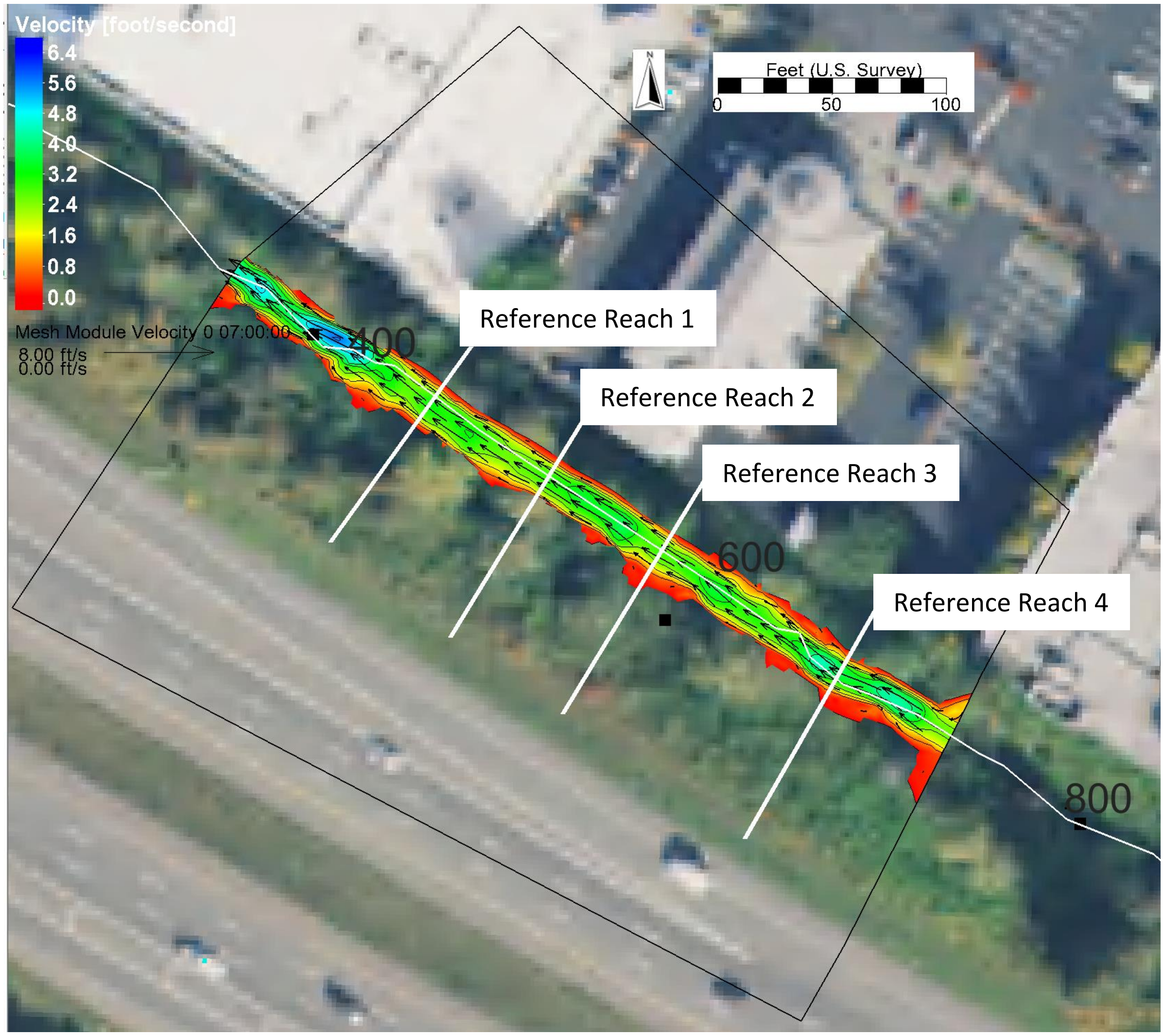

Figure 55: Existing reference reach conditions 100-year velocity map with cross-section locations

Table 10: Existing conditions velocities including floodplains at select cross-sections

	Q100 Average Velocities (ft/s)		
	LOB*	**Main Ch**	**ROB***
Reference Reach 1	0.48	3.16	0.51
Reference Reach 2	0.56	2.44	0.51
Reference Reach 3	0.32	2.43	1.21
Reference Reach 4	0.52	2.75	1.23
Immediately Upstream of Structure 1	1.02	1.71	0.47
Immediately Upstream of Structure 2	0.69	1.63	0.51
Through Structure 1	N/A	3.85	N/A

*ROB/LOB locations determined from Existing Conditions Q2 extent

Table 11: Existing conditions 100-year overflow velocities including floodplains at select cross-sections

	Q100 Overflow Average Velocities (ft/s)		
	LOB*	Main Ch	ROB*
Reference Reach 1	2.43	5.49	1.74
Reference Reach 2	2.04	4.87	1.76
Reference Reach 3	2.53	6.02	2.78
Reference Reach 4	2.35	6.26	2.41
Immediately Upstream of Structure 1	0.49	2.55	2.23
Immediately Upstream of Structure 2	0.61	2.55	2.23
Through Structure 1	N/A	4.71	N/A

*ROB/LOB locations determined from Existing Conditions Q2 extent

The downstream reference reach that has signs of previous restoration efforts was also modeled based on LiDAR (OCM Partners, 2020), from Sta. 4+50 to 7+25 in order to determine hydraulic properties of the reference reach. Roughness values, boundary conditions parameters, and model run controls of the existing conditions model were used. Given the high degree of anthropogenic modification of this reach, certain design parameters were required to compare to a reference reach model.

4.3 Channel Design

4.3.1 *Floodplain Utilization Ratio*

The Floodplain Utilization Ratio (FUR) was calculated by dividing the flood-prone width (FPW) as defined by the 100-year inundated area by the field-determined bankfull width (nine feet). This was repeated at four cross-sections along the reference reach and averaged to get a final FUR.

Table 12 Flood-prone width and FUR calculations within the reference reach

Location	Flood-prone Width [feet]	FUR
Reference Reach 1	23.4	2.6
Reference Reach 2	28.6	3.2
Reference Reach 3	19.5	2.2
Reference Reach 4	22.7	2.5
Average	23.6	2.6

The Unnamed Tributary to Tibbetts Creek falls between FUR of 2 and 3, indicating that it is a moderately confined channel. Previous modifications of this reach have significantly influenced the FUR, such as construction of I-90 to the south and the previous ditching observed from GLO maps from 1977 (http://wagda.lib.washington.edu/Aerials/pdf/ISSAQ-IC1.pdf). Modification of this reach has likely increased the confinement, and the slope and location of the reach would typically indicate an unconfined system; however, the adjacent land is significantly built up such that restoring this reach to an unconfined system would not be practical to tie into adjacent reaches. Since the FUR has been altered from a historic/ natural state channel design considers the velocity ratio requirements of an unconfined channel (Table 22).

It should be noted that the 100-year non-overflow flow was used to determine the FUR, not the 100-year overflow from Issaquah Creek, since in existing conditions only approximately 110 cfs of the overflow reaches the reference reach. However, in future conditions, a greater portion of the overflow will be conveyed through I-90 MP 16.21.

4.3.2 *Channel Planform and Shape*

The WCDG recommend that a proposed stream channel should have a gradient, cross-section, and general configuration that is similar to the existing channel upstream and downstream of the proposed crossing, provided that the adjacent channel has not been modified in ways that adversely affect natural stream processes. Existing conditions for Unnamed Tributary to Tibbetts Creek were evaluated upstream and downstream of the I-90 crossing (Section 4.2). The proposed channel configuration was designed to mimic the natural channel conditions observed in the reference reach. A low flow channel will be added in later stages of the project that connects habitat features together so that the project is not a low flow barrier. The low flow channel will be as directed by the Engineer in the field.

A typical section of the Unnamed Tributary to Tibbetts Creek within the reference reach is shown in Figure 57. The reference reach typical section consists of a 9-foot bankfull width, with a 5-6-foot channel bottom, steep channel sides, then typically a 4-5 foot slightly sloped bench. The right bank side typically has a shorter bench and a steeper side slope, whereas the left bank tends to have a wider bench and a less steep embankment (Figure 22). The proposed channel cross-section is designed to mimic the reference reach cross-section with two differences. The first difference is that the bank slopes up to the bankfull bench are steeper than construction allows; therefore, the channel bottom is slightly smaller with a less steep slope up to bankfull (Figure 57). This section is expected to deform over time and scour out the toe of the bank, widening the channel and closely approximating the reference reach cross-section. The second difference is the width of the bench. A total of eight feet of bench is used in the proposed section to meet the 17-foot minimum hydraulic opening, slightly reducing the confinement of the channel.

As stated in Section 4.2, the 2-year flow tends to simulate significantly higher than the bankfull bench (Figure 53); therefore, it is expected that the proposed cross-section will also include a 2-year flow that simulates relatively high for the 2-year event. Bankfull depth was used in the proposed channel cross-section to maintain similar bankfull characteristics.

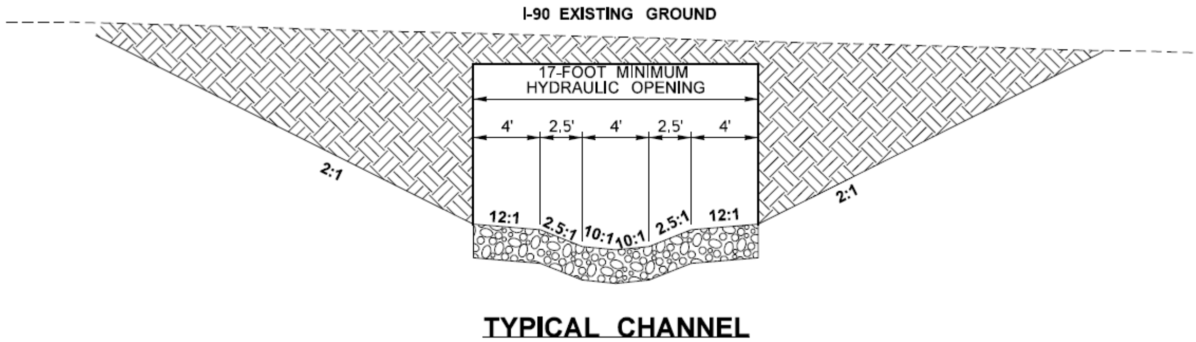

Figure 56: Design cross-section

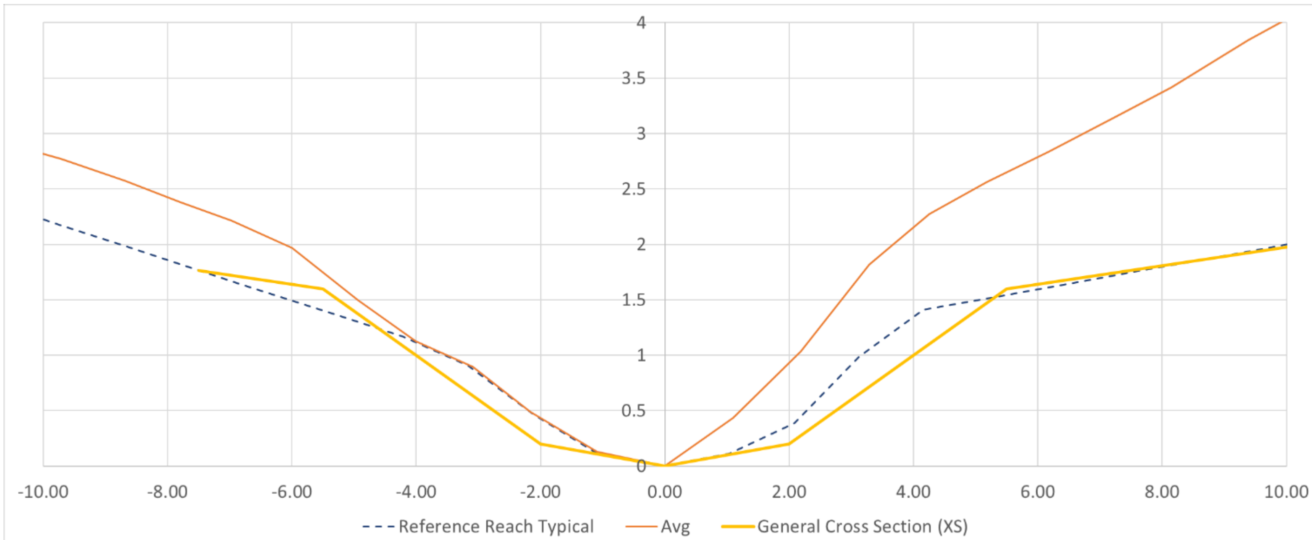

Figure 57: Comparison of design cross-section (yellow), average existing cross-section (orange), and typical reference reach cross-section (dashed)

4.3.3 *Channel Alignment*

The proposed stream realignment begins approximately 67 feet downstream of the existing culvert and extends to approximately 60 feet upstream of the existing culvert, grading about 507 linear feet of channel, including the I-90 MP 16.21 crossing. The channel is designed to mimic the existing meander radii and overall planform geometry of the Unnamed Tributary to Tibbetts Creek.

Alignment constraints include private parking lots and buildings upstream and downstream of the crossing. The available channel area is able to accommodate the proposed cross-section without encroaching on these.

The proposed alignment includes a daylighted section between I-90 and Gilman Boulevard. This will allow more light into the crossing and reduce the individual crossing lengths, representing a benefit for habitat and fish use.

4.3.4 *Channel Gradient*

The WCDG recommend that the proposed stream channel gradient not be more than 25 percent steeper than the natural channel gradient (WCDG Equation 3.1). The proposed channel for the Unnamed Tributary to Tibbetts Creek provides a constant gradient of 0.30 percent through the crossing. This is less than 125 percent of the 0.45 percent slope of the reference reach (Section 2.8.1), and less than the 0.50 percent slope of the upstream reach. The proposed gradient of 0.30 percent is slightly less than the reference reach slope; potential for aggradation is discussed in Section 8.2. In order to tie into the downstream reach, which has a slope that is relatively flat compared to the reference reach, the proposed slope represents a balance between equilibrium and existing conditions. It is expected that the wider opening will reduce backwater, clearing out downstream sediment such that the proposed condition is able to equilibrate.

Channel gradient also dictates whether additional stream stability measures need to be taken to ensure that a proposed channel through a structure maintains its shape and does not become entrained along a structure wall. Per the WCDG, if the longitudinal bed slope through a culvert is less than 4 percent, then coarse bands, larger material along the sides of the culvert, or similar channel shaping measures are recommended. The Unnamed Tributary to Tibbetts Creek has a proposed bed slope below 4 percent. Therefore, as directed by the WCDG, channel complexity designed to prevent entrainment will be installed inside the proposed culvert. The size of material and the number of coarse bands is further discussed in Section 5.2.1.

4.4 Design Methodology

The proposed fish passage design was developed using the 2013 Water Crossing Design Guidelines and the WSDOT Hydraulics Manual. Using the guidance in these two documents, the Stream Simulation design method was determined to be the most appropriate at this crossing because the bankfull width, FUR, and channel stability fell within the applicable ranges, as described in detail below.

For Unnamed Tributary to Tibbetts Creek, the design BFW was 9 feet and based on reference reach observation (Section 2.8.1). The WCDG methodology for designing a stream simulation structure is defined by the FUR, bankfull width (Section 2.8.2), channel gradient (Section 4.4.4), channel shape (Section 4.3.2), length of crossing (Section 4.4.3), channel stability (Section 2.8.4), and channel migration (Section 2.8.5).

For stream simulation design, the WCDG recommend sizing the span of a proposed structure based on the agreed upon BFW, with the span being 1.2 x bankfull width + 2 feet (WCDG Equation 3.2). For the Unnamed Tributary to Tibbetts Creek crossing, using this equation with the agreed upon BFW of 9 feet, the minimum hydraulic opening should be 12.8 feet, or 13 feet (rounded to the nearest whole foot) based on standard culvert structure sizes. However, the WCDG also recommend that the length of a stream simulation structure should be checked against its span. If the structure is a culvert and the ratio of the culvert length to the culvert span is greater than 10, it is considered a long culvert and special design considerations are necessary. Specifically, the minimum hydraulic opening width should be increased by 30 percent. The length of the proposed I-90 crossing compared to the minimum hydraulic opening does exceed a ratio of 10. Furthermore to accommodate the Gilman Boulevard Overflow event while meeting design requirements, it is necessary to add additional width of 4 feet to the proposed structure.

4.5 Future Conditions – Proposed 17-Foot Minimum Hydraulic Opening

The hydraulic opening is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic opening assumes vertical walls at the edge of the minimum hydraulic opening width unless otherwise specified.

The starting point for the design of all WSDOT structures is equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic opening of 17 feet was determined to be the minimum starting point.

This section presents key results from the hydraulic analysis of I-90 MP 16.21 crossing with the proposed minimum hydraulic opening of 17 feet. The calculated WSE, velocity, and depth from the proposed conditions SRH-2D model for the 2-, 100-, 500-year, 2080 predicted 100-year peak flows, 100-year overflow, and 500-year overflow are presented in Appendix C - SRH-2D Model Results. The WSEs along the proposed Unnamed Tributary to Tibbetts Creek thalweg for the same peak flows are depicted in Figure 58 as well. As depicted in the figure, the model results indicate that the 17-foot minimum hydraulic opening reduces the backwater caused by the existing structure for all peak flows.

Table 13 contains the WSE and shear stress at the proposed structure's estimated upstream and downstream ends during the 2-, 100-, 500-year, 2080 predicted 100-year, 100-year overflow, and 500-year overflow peak flows. It also contains the average velocities in the channel upstream of the structure and through the typical proposed channel section for the same peak flows. The velocity through the proposed crossing is estimated as the average of the velocities along the cross-sections within the estimated limits of the proposed structure. The average velocity in the reach upstream of the I-90 MP 16.21 crossing is estimated as the average of the velocities along the cross-sections between Stations 10+18 and 14+20. The average velocities within the proposed I-90 MP 16.21 crossing are comparable in magnitude to the velocity in the reference reach for all examined peak flows (Table 14). This suggests that the proposed 17-foot minimum hydraulic opening structure and associated in-channel grading promotes flow conditions, which will help maintain natural stream processes. This includes the continuity of flow and its capacity to transport wood and sediment through the proposed crossing.

The 2-year simulation results tend to show depth significantly above bankfull; this was observed under existing conditions as well. Given that the bankfull depth and the simulated 2-year depth are consistent between existing and proposed conditions, the 2-year channel is shown to be consistent with existing condition morphology. The two downstream channel constrictions observed under existing conditions are also observed for the 2- and 100-year proposed conditions. These channel constrictions create backwater under the proposed crossing, but not enough to impact the structure. The 100-year overflow is completely contained within the channel; however, the 500-year overflow event spills out of the channel, occupying Gilman Boulevard and conveying flow to the crossing downstream to the northwest (approximately 60 cfs). The 100- and 500-year flow simulations indicate that channel constrictions do not impact the water surface profile significantly during these events.

Table 13: Average main channel hydraulic results for proposed condition upstream and downstream of structure (Upstream 2 and Downstream 1, Figure 60)

Event ($\boldsymbol{Years}$)	WSE (ft)		Depth (ft)		Velocity ($\frac{ft}{s}$)		Shear ($\frac{\boldsymbol{lb}}{\boldsymbol{ft^2}}$)	
	US	*DS*	*US*	*DS*	*US*	*DS*	*US*	*DS*
2	50.48	50.32	1.3	1.46	1.58	0.38	0.08	0.01
100	51.22	51.03	2.04	1.83	2.05	0.48	0.12	0.02
500	51.56	51.37	2.76	2.04	2.24	0.67	0.13	0.04
2080 Predicted 100	51.83	51.45	3.11	2.22	2.43	0.93	0.15	0.06
100 Overflow	55.35	54.03	4.69	4.21	3.88	2.00	0.60	0.28
500 Overflow	58.55	55.16	4.21	5.35	2.85	3.64	0.47	0.88

Table 14: Average main channel hydraulic results for proposed condition within crossing structure

Event ($\boldsymbol{Years}$)	WSE ($\boldsymbol{ft}$)	Depth ($\boldsymbol{ft}$)	Velocity ($\frac{\boldsymbol{ft}}{\boldsymbol{s}}$)	Shear ($\frac{\boldsymbol{lb}}{\boldsymbol{ft^2}}$)
2	50.44	1.44	1.40	0.07
100	51.17	2.18	1.84	0.10
500	51.50	2.36	1.99	0.16
2080 Precited 100	51.72	2.87	2.13	0.21
100 Overflow	54.95	5.96	5.67	0.69
500 Overflow	57.85	5.31	2.73	0.71

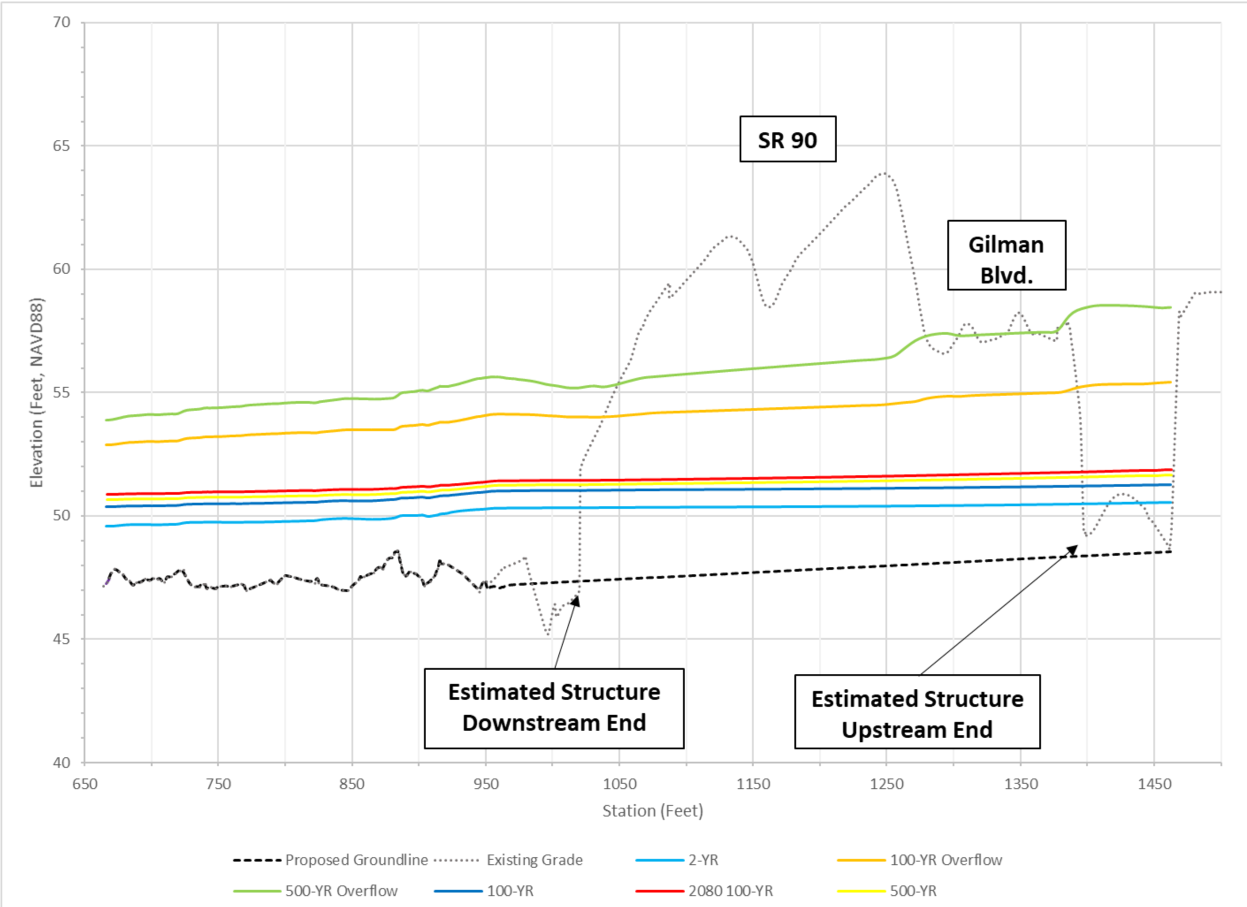

Figure 58: Proposed conditions water surface profiles

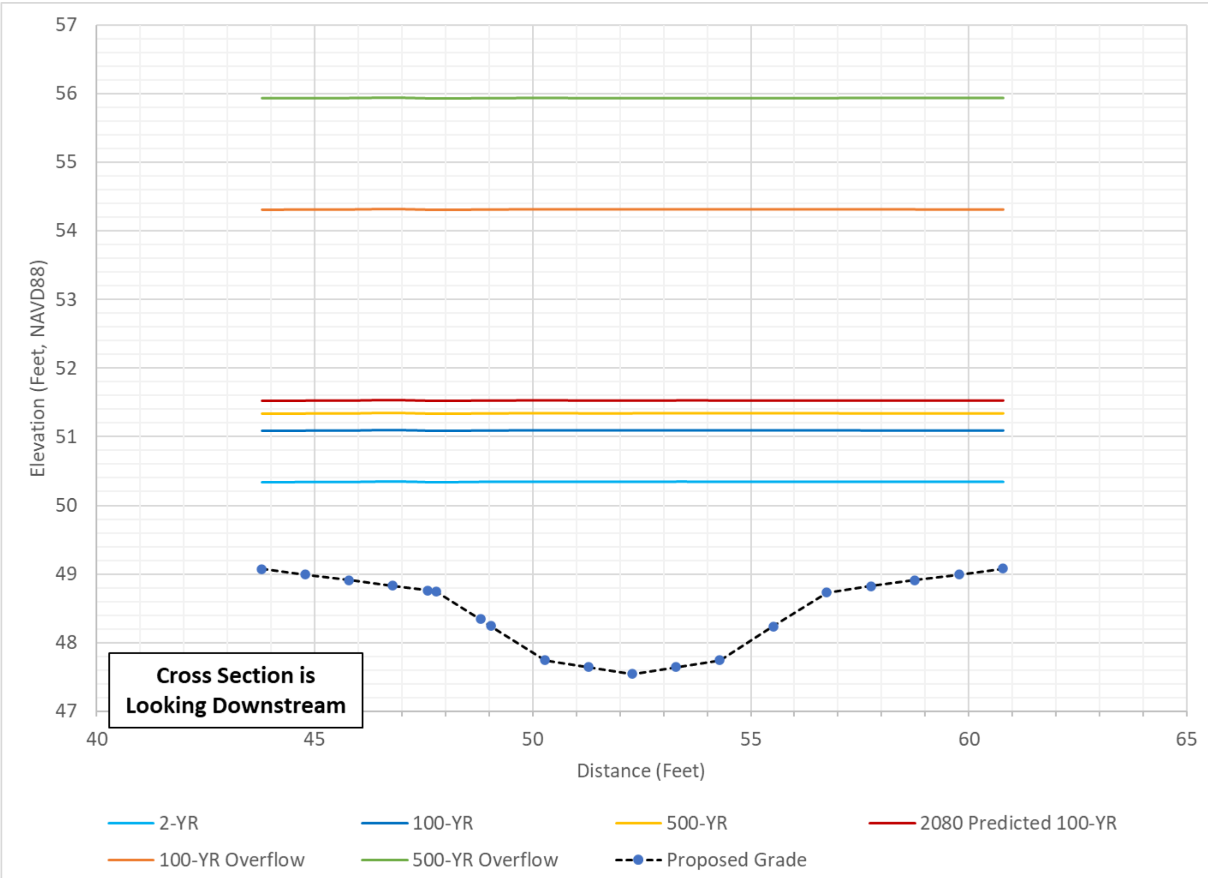

Figure 59: Typical section through proposed structure

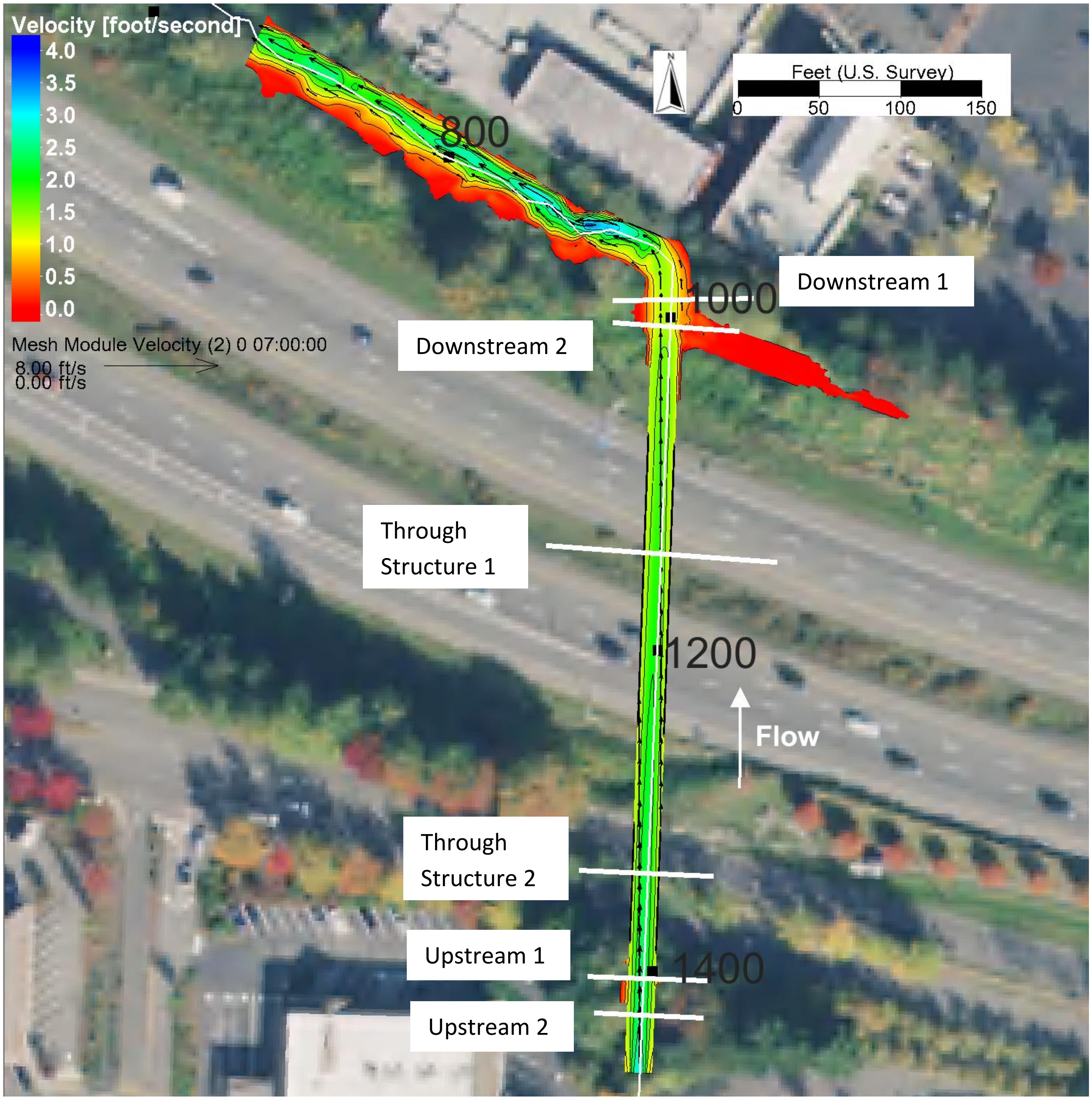

Figure 60: Proposed conditions 100-year velocity map

Table 15: Proposed velocities including floodplains at select cross-sections

	Q100 Average Velocities (ft/s)		
	LOB*	Main Ch	ROB*
Reference Reach 1	0.56	2.44	0.51
Reference Reach 2	0.32	2.42	1.21
Reference Reach 3	0.32	2.75	1.23
Reference Reach 4	0.48	3.16	0.51
Immediately Upstream of Structure 1	1.22	2.06	1.21
Immediately Upstream of Structure 2	1.35	2.12	1.34
Through Structure 1	0.96	1.93	1.05
Through Structure 2	1.03	1.66	0.96

*ROB/LOB locations determined from Proposed Conditions Q2 extent

Table 16: Proposed velocities including floodplains at select cross-sections

	2080 Predicted Q100 Average Velocities (ft/s)		
	LOB*	Main Ch	ROB*
Reference Reach 1	0.48	3.16	0.51
Reference Reach 2	0.56	2.44	0.51
Reference Reach 3	0.32	2.42	1.21
Reference Reach 4	0.52	2.75	1.23
Immediately Upstream of Structure 1	0.77	2.33	0.83
Immediately Upstream of Structure 2	0.82	2.40	0.79
Through Structure 1	1.19	2.20	1.30
Through Structure 2	1.28	1.94	1.20

*ROB/LOB locations determined from Proposed Conditions Q2 extent

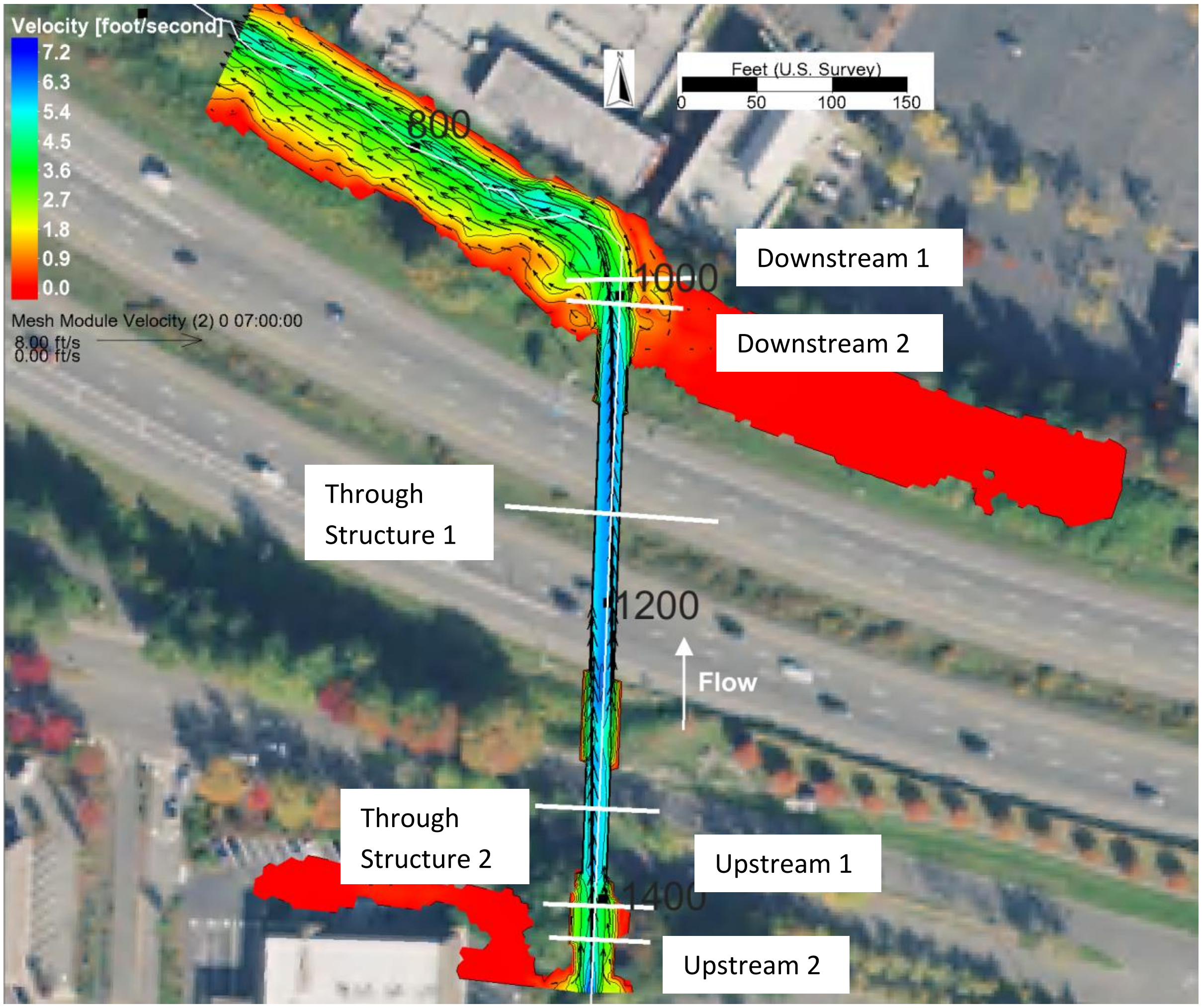

Figure 61: Proposed conditions 100-year overflow velocity map

Table 17: Proposed velocities including floodplains at select cross-sections

	Q100 Overflow Average Velocities (ft/s)		
	LOB*	Main Ch	ROB*
Reference Reach 1	2.43	5.49	1.74
Reference Reach 2	2.04	4.87	1.76
Reference Reach 3	2.53	6.02	2.78
Reference Reach 4	2.35	6.26	2.41
Immediately Upstream of Structure 1	2.37	4.62	2.68
Immediately Upstream of Structure 2	1.88	4.4	2.80
Through Structure 1	3.71	5.57	3.99
Through Structure 2	4.53	5.97	4.30

*ROB/LOB locations determined from Proposed Conditions Q2 extent

A sensitivity test of the Manning's n roughness coefficient was performed to evaluate the resilience of the design. This used the proposed condition SRH-2D model to test how simulated results change when using a different composite Manning's n value for the channel reach where LWM is proposed. As discussed in Section 4.1.3, a composite Manning's n of 0.055 was selected to represent increased roughness for the entire width of the channel for the section where additional LWM is proposed. For the sensitivity test, this value was varied by adding and subtracting 0.02. The effect of changing the n value for the 2-year (low flow) and 100-year (high flow) conditions at both the upstream and downstream end of the crossing are presented in Table 18 through Table 21.

This analysis showed that the simulation results are not very sensitive to the composite Manning's n value at either the upstream or downstream ends of the crossing, or at the 2- or 100-year flows. Water surface elevation and depth changed by less than 0.2-foot in all cases evaluated. Likewise, there was relatively insignificant changes to velocity and shear stress. This indicates that using even up to a +/- 0.02 change in Manning's n value would not lead to a significant change in the proposed design. Given the relatively low slope and the distribution of proposed LWM (mostly downstream of crossing), the low sensitivity to Manning's n values is expected for this crossing.

Table 18: Average main channel hydraulic results at the upstream face of the structure for Manning's n sensitivity test of +0.02 compared to proposed conditions

Event ($\boldsymbol{Years}$)	WSE (ft)		Depth (ft)		Velocity ($\frac{ft}{s}$)		Shear ($\frac{\boldsymbol{lb}}{\boldsymbol{ft^2}}$)	
	US	*Difference*	*US*	*Difference*	*US*	*Difference*	*US*	*Difference*
2	50.58	0.01	1.58	0.02	1.6	-0.02	0.11	0
100 (Overflow)	55.92	0.1	6.93	0.09	4.81	-0.09	0.73	-0.03

Table 19: Average main channel hydraulic results at the upstream face of the structure for Manning's n sensitivity test of -0.02 compared to proposed conditions

Event ($\boldsymbol{Years}$)	WSE (ft)		Depth (ft)		Velocity ($\frac{ft}{s}$)		Shear ($\frac{\boldsymbol{lb}}{\boldsymbol{ft^2}}$)	
	DS	*Difference*	*DS*	*Difference*	*DS*	*Difference*	*DS*	*Difference*
2	50.55	-0.02	1.55	-0.01	1.63	0.01	0.11	0
100 (Overflow)	55.83	0.01	6.85	0.01	4.89	-0.01	0.75	-0.01

Table 20: Average main channel hydraulic results at the downstream face of the structure for Manning's n sensitivity test of +0.02 compared to proposed conditions

Event ($\boldsymbol{Years}$)	WSE (ft)		Depth (ft)		Velocity ($\frac{ft}{s}$)		Shear ($\frac{\boldsymbol{lb}}{\boldsymbol{ft^2}}$)	
	US	*Difference*	*US*	*Difference*	*US*	*Difference*	*US*	*Difference*
2	50.41	0.03	2.19	0.02	1.17	-0.01	0.05	0
100 (Overflow)	54.33	0.18	6.35	0.18	5.88	-0.24	1.05	-0.12

Table 21: Average main channel hydraulic results at the downstream face of the structure for Manning's n sensitivity test of -0.02 compared to proposed conditions

Event ($\boldsymbol{Years}$)	WSE (ft)		Depth (ft)		Velocity ($\frac{ft}{s}$)		Shear ($\frac{\boldsymbol{lb}}{\boldsymbol{ft^2}}$)	
	DS	*Difference*	*DS*	*Difference*	*DS*	*Difference*	*DS*	*Difference*
2	50.37	-0.01	2.15	-0.02	1.19	0.01	0.06	0.01
100 (Overflow)	54.16	0.01	6.17	0	6.12	0	0.88	-0.29

4.6 Water Crossing Design

4.6.1 *Structure Type*

No structure type has been recommended by Headquarters Hydraulics. The layout and structure type will be determined at later project phases.

4.6.2 *Minimum Hydraulic Opening Width and Length*

Based on the factors described above, a Minimum Hydraulic Opening of 17 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. The Minimum Hydraulic Opening of 17 feet results in a design ratio of Minimum Hydraulic Opening to Bankfull width (i.e., factor of safety) of 1.9. The increased hydraulic opening to accommodate overflows from Issaquah Creek as well as additional channel complexity features to allow increased meandering within the crossing. The 100-year, projected 2080 100-year flow, and 100-year overflow event was evaluated and the velocity comparisons for these flow rates can be seen in Table 22 below. Since this is a confined system the velocities for the 100-year overflow event were compared between the proposed condition and the reference reach, and the velocity ratio of the main channel was designed to be less than 1.1, showing that the velocities through the structure do not differ greatly from adjacent reaches.

Table 22: Velocity comparison for 17-foot structure

	100-Year Velocity (ft/s)	2080 Predicted 100-Year Velocity	Difference (ft/s)	Overflow 100-Year Velocity (ft/s)
Upstream of Structure	**2.2**	**2.4**	**0.2**	**4.5**
Through Structure	**1.8**	**2.1**	**0.3**	**5.8**
Downstream of Structure	**1.2**	**1.4**	**0.2**	**4.4**
Velocity Ratio	**0.8**	**0.8**	**0.0**	**1.02**

No additional size increase was determined to be necessary to accommodate climate change. Due to the increase in width to accommodate the Issaquah Creek overflows, the size was determined by analysis to be adequate for future climate change flows.

A Minimum Hydraulic Opening of 17 feet is recommended up to a maximum structure length of 376 feet (existing structure length). Because the Minimum Hydraulic Opening has already been increased due to the long culvert length, at 376 feet the crossing will need to be reevaluated to determine if a width increase is necessary.

4.6.3 *Freeboard*

The WCDG recommend the prevention of excessive backwater rise and increased main channel velocities during floods that might lead to scour of the streambed and coarsening of the stream substrate, allow the free passage of debris expected to be encountered, and generally suggest a minimum three-foot freeboard for streams of this size above the 100-year water surface elevation. WSDOT is incorporating climate resiliency in freeboard, where practicable, and has evaluated freeboard at both the 100-year water surface elevation and the projected 2080 100-year water surface elevation.

The minimum required freeboard at this location based on bankfull width was two feet at the 100-year flow event. The water surface elevation is projected to increase 0.4 feet for the 2080 projected 100-year flow rate. The overflow rates are significantly higher than the 2080 predicted 100-year flow and therefore will be used if it is practicable to do so. A minimum of six feet between the channel thalweg elevation and inside top of structure is recommended for maintenance and monitoring purposes, however freeboard should be maximized where practical depending on structure type and size.

Long-term degradation, aggregation, and debris risk were also evaluated at this location. One foot of freeboard was added to the structure to account for the risk of aggradation/debris risk (Section 2.8.4). Two feet of countersink shall be maintained at a minimum to account for degradation (Section 2.8.4). More information on the risk for long-term degradation and aggradation can be found in Section 8. The roadway low point in WB I-90 is at 60.6 feet, the roadway low point on EB I-90 is at 59.1 feet, the elevation required to meet freeboard requirements for these locations is 58.5, and 58.2 feet, respectively. Indicating that freeboard requirements will be able to be met including an assumed 14 inches of road thickness. Given the uncertainty associated with the Issaquah Creek Overflow and beaver dam activity, freeboard should be maximized once the roadway thickness is known at the FHD phase.

4.6.3.1 Past Maintenance Records

As discussed previously (Section 2.7.2), WSDOT Area Maintenance was contacted to determine whether or not there were ongoing maintenance problems at the existing structure due to LWM racking at the inlet or sedimentation. The maintenance representative indicated there was not a record of LWM blockage and/or sediment removal at this crossing.

4.6.3.2 Wood and Sediment Supply

Wood recruitment for the I-90 MP 16.21 crossing is low, and the majority of the upstream trees are relatively small (< 1-foot DBH) and sparse. The watershed is mostly urbanized and ditches and upstream culverts prevent wood supply. However, if an overflow occurs from Issaquah Creek, there is a potential for higher sediment, debris, and LWM flow reaching the crossing.

Sediment supply to the crossing consists of mostly fine material and small gravel (Section 2.8.3). The quantity of sediment based on the site visit appears to be sufficient to form deposits and bars (Figure 14).

4.6.3.3 Flooding

Flooding has been observed in the vicinity several times, notably in February 2020 and January 2009 (Issaquah Press, Jan 14, 2009). However, flooding has not been observed at this particular site. The FIS (FEMA, 2010) indicates that the Gilman Boulevard Overflow will be activated at a flow of between 2,890 and 3,400 cfs at USGS gage 12121600, which has only occurred twice since the gage has been established, in 1987 and 1990. In each case, flows did not exceed 3,400 and there is no record of flood extents extending to this crossing.

4.6.3.4 Future Corridor Plans

The only listed future plan in the vicinity of this project is the I-90 - Eastgate to SR 900 - Corridor Improvements, which does not include widening the highway.

4.6.3.5 Impacts

Raising the road in the vicinity of the structure is not anticipated at this phase.

5 Streambed Design

5.1 Bed Material

The development of the proposed streambed mix followed methods recommended by WDFW for sizing streambed material in culverts, the WSDOT Hydraulics Manual (WSDOT, 2019), and the FHWA for determining incipient motion for streambed particles. The proposed streambed mix design was proportioned to mimic Pebble Count 3 and 4 collected in the reference reach of the project (see Section 2.8.3). The streambed material gradation was proportioned to mimic natural conditions, from the larger particle sizes while also including smaller, more mobile particle sizes in order to produce a porosity that minimizes the opportunity for flow in the stream to go entirely subsurface during late summer and early autumn low flow periods. The finer portion of the gradation will be comprised of silts, sands, and small gravels to fill the interstitial spaces of the larger portions of the gradation.

The Bathurst method as recommended by WDFW, as well as being a preferred method for many stream crossing design practitioners, is not recommended for use in streams with gradients less than four percent. The design slope for the proposed Unnamed Tributary to Tibbetts Creek crossing of I-90 is 0.3 percent (see Section 4.3.4). Therefore, the Bathurst method was not utilized for assessing the streambed material. The Modified Shield's method as described in the US Forest Service Stream Simulation guidelines (USDA, 2008) was utilized to verify whether the proposed sediment sizes are mobile or stable as intended during the full range of design flows. This was achieved by comparing the critical shear stress for incipient motion of each size fraction of the proposed streambed mixture to the average applied shear stress within the proposed grading limits for each examined peak flow.

The proposed streambed material should be constructed utilizing WSDOT Standard Specifications and Aggregates for Streams, Rivers, and Waterbodies special provision (WSDOT, 2020). Specifically, 75 percent of Streambed Sediment (Section 9-03.11(1)) mixed with 25 percent six-inch Streambed Cobble grading (Section 9-03.11(2)) should be utilized, ultimately producing a well-graded mix. Twenty five percent six-inch cobble was added to increase the D_{50} to more closely approximate the reference reach but will include sediment larger than the D_{100}. HQ Hydraulics recommends that, in addition to the 75 percent Streambed Sediment, Streambed Sand (per WSDOT Special Provision – Aggregates for Streams, Rivers, and Waterbodies) be included, where necessary during construction, to ensure that all voids are filled to minimize the potential for low flows disappearing into the stream subsurface. The minimum streambed depth will be determined based on scour calculations during later stages of design.The final combined gradation for the proposed streambed mix design was calculated utilizing a spreadsheet developed by WDFW and WSDOT that uses methods presented in Bunte and Abt (2001). The calculated proposed streambed material gradation is summarized in Table 23 and the relevant calculations are provided in in Appendix D - Streambed Material Sizing Calculations. A comparison of the streambed material design gradation to the calculated gradation and the reference reach Pebble Count 3 and 4 is presented in Figure 62.

The proposed streambed mix has a 0.8-inch median diameter, D_{50}, (Table 23), which is within 20 percent of the 1.0-inch, D_{50} of Pebble Count 3 and 4 collected in the reference reach (see Section 2.8.3 and Table

23). Therefore, the proposed design does satisfy the WAC 220-660-190 requirement that the D_{50} of the design mix must be within 20 percent of the existing streambed material D_{50}. Sediment mobility through the regrade is typically stable during non-overflow events. The D_{50} and the D_{84} become mobile during the 50-year overflow event and the D_{100} is mobile above the 100-year overflow event (Appendix D - Streambed Material Sizing Calculations).

Table 23: Comparison of observed and proposed streambed material

	Average Diameter (in)	Proposed Diameter (in)
D_{16}	0.4	0.4
D_{50}	1.0	0.8
D_{84}	1.5	1.9
D_{95}	1.6	5.0
D_{100}	5.0	6.0

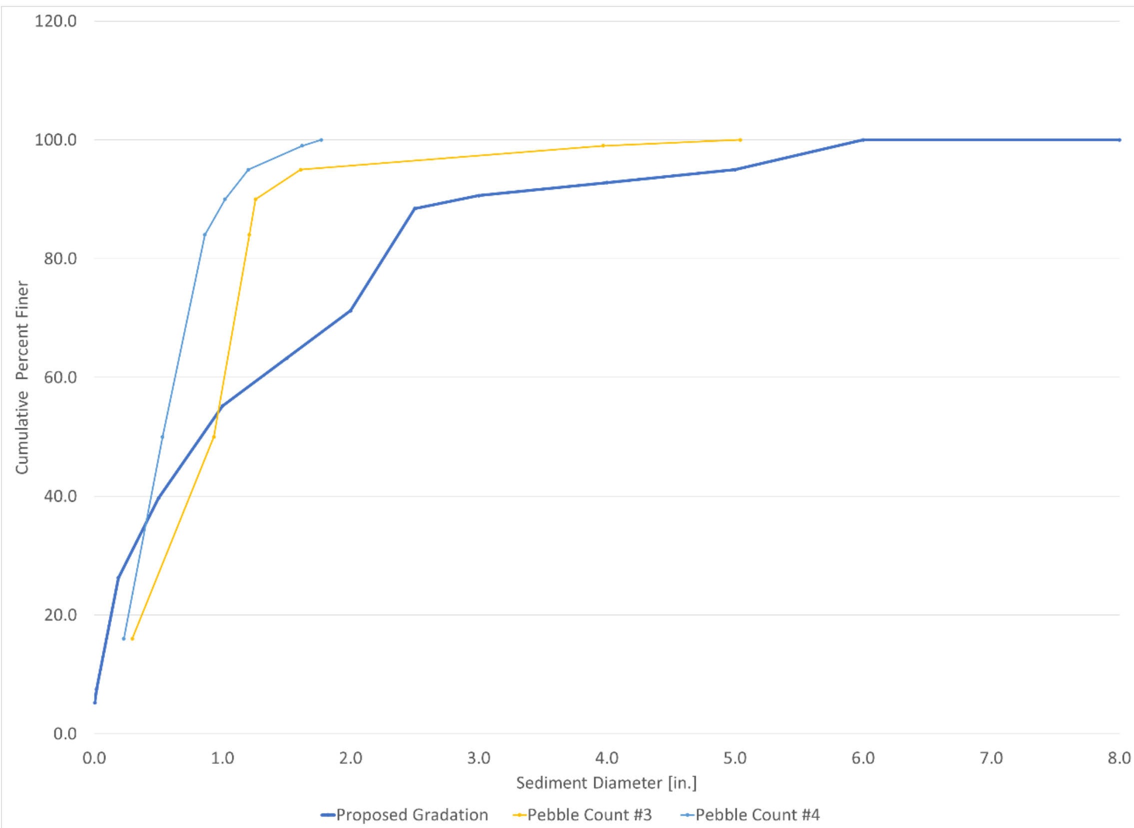

Figure 62: Comparison of proposed streambed gradation and pebble count

5.2 Channel Complexity

5.2.1 *Design Concept*

Channel complexity features for the I-90 MP 16.21 crossing are designed for current habitat conditions and allow for natural stream processes. The channel complexity features utilized for this crossing include LWM and meander bars.

Due to the relatively long length of the crossing and short regrade area outside of the crossing, in order to meet the 75th percentile Fox and Bolton (2007) requirements (Table 24), LWM placement outside of the regrade area is proposed. LWM outside of the regrade area focuses on self-ballasting pieces that extend up the steeper side slopes; this minimizes the impact or excavation and access in areas outside of the regrade. Upstream of the crossing, 2-foot DBH 12-foot-long logs were exclusively used. The intent of this is to decrease the risk of racking within or at the entrance of the upstream crossing inlet. Orientation and placement of the LWM is consistent with the habitat requirements of the project site. Though channel spanning wood was used in previous restoration projects in the downstream reach, channel spanning wood has the potential to become a fish passage barrier and was not proposed for this crossing. LWM projecting from the stream up a steep bank will still need to be analyzed for stability at a later phase. LWM material was designed with aquatic habitat and stream processes considered. The presence of Smallmouth Bass as a potential predator of salmonids pushes the LWM design away from complex multi-log structures that provide lurker-predator cover. However, multi-log structures that are vaulted and allow for visibility should mitigate predation. King County, Trout Unlimited, and the Lake Sammamish Kokanee Working Group have collaborated on restoration projects focused on Lake Sammamish Kokanee and other species in the region (King County, 2011a; King County, 2011b; Lake Sammamish Kokanee Working Group, 2014). Evaluating the needs of species of concern in this reach, LWM design incorporated habitat features of the aquatic species that have the possibility of utilizing this reach (Table 1). The design also incorporates geomorphological and habitat characteristics based on stream size and location (Fox and Bolton, 2007 and Fox, 2003). Given that this is a relatively small stream (less than 15 feet BFW) that is confined, the majority of naturally derived key pieces are likely to be windthrow. The majority of the pieces are likely to reside either entirely or partially in Zone 1 and Zone 2. Since no channel spanning wood is proposed, a greater proportion of pieces oriented with the rootwad toward the thalweg were included in the stream, which deviated from reference streams of this size. This design incorporates the needs of species that prefer underbank type habitat. Excavated preformed scour pools shall be constructed at all rootwads interacting with the stream below bankfull.

Table 24: Summary of Fox and Bolton (2007) targets and design LWM

WSDOT Large Woody Material for stream restoration metrics calculator				
State Route# & MP	SR90 MP 16.21	Key piece volume	1.310	yd3
Stream name	Unnamed Tributary to Tibbetts Creek	Key piece/ft	0.0335	per ft stream
length of regrade[a]	507 ft	Total wood vol./ft	0.3948	yd3/ft stream
Bankfull width	9 ft	Total LWM[c] pieces/ft stream	0.1159	per ft stream
Habitat zone[b]	Western WA			

Log type	Diameter at midpoint (ft)	Length(ft)[d]	Volume (yd^3/log)[d]	Rootwad?	Qualifies as key piece?	No. LWM pieces	Total wood volume (yd^3)
A	1.5	21	1.37	yes	yes	16	21.99
B	1.75	15	1.34	yes	yes	18	24.05
C	2	12	1.40	yes	yes	22	30.72
D	2	18	2.09	yes	yes	24	50.27
E	1.3	7	0.32	no	no	13	4.14
F	2.3	13	1.91	no	yes	23	44.03
G	1.0	14	0.41	no	no	11	4.48
H	2.5	6	1.09	no	no	19	20.73
I			0.00				0.00
J			0.00				0.00
K			0.00				0.00
L			0.00				0.00
M			0.00				0.00
N			0.00				0.00
O			0.00				0.00
P			0.00				0.00

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	103	146	200.4
Targets	17	59	200.2
	surplus	surplus	surplus

Mobile Woody Material (MWM) was considered but determined to be a risk due to the small diameter private crossing downstream of the crossing location. Coir logs and willows should be used along bankfull benches to stabilize the bank immediately following construction.

Coarse bands were not determined to be beneficial for aquatic habitat in this reach. Low flow meander bars are proposed on the inside of low flow meanders within the structure. They will consist of well-graded stream bed sediment that is one to two times D_{100} (the largest particle found in the bed). Fine bands consisting of Streambed Fine Sediment, a natural or manufactured sand, meeting the grading requirements (WSDOT, 2019) shall be placed around meander bars to prevent piping. The intent of the meander bars is not to encourage planform meandering but to prevent entrainment and plane-bed formation, as well as to provide velocity breaks for aquatic species. Low flow meander bars will be installed following a modified version of bendway weirs/stream barbs from FHWA (2009). The angle of projection between the bar axis and upstream bankline is 45 degrees. The length of the bars will be six feet, and project just beyond the thalweg, and three additional feet will be keyed into the overbank at a depth equal to D_{100}. The height of the bar will transition from the height of the overbank at the bank to 0.6 feet high at the thalweg at a slope of between five to eight percent. The top width of the bars is proposed to be three feet at the intersection with the bank, transitioning down to one foot near the thalweg, allowing two to three boulders at the D_{100} size to be utilized. The meander bar will consist of a core consisting of the one- to two-times the D_{100}; the streambed mix will be used to smoothly transition to and from the core dimensions back to the typical stream section, over the course of the entire meander. The spacing for the meander bars was determined based on the meander belt width (USGS, 1986). Because the channel is moderately confined, typical meander function may not be applicable. The meander bar spacing based on meander belt width was also checked against meander wavelength observed in the reference reach and resulted in a wavelength of 45 feet.

Replanting design for this crossing should maximize shade cover to preclude reed canary grass reestablishment. Due to beaver presence in the area, PEO should plan for mitigation of potential negative impacts of beaver dams during the FHD phase.

The streambed design mix was also checked for consistency with the spawning gravels required by present species. The proposed mix includes 31 percent substrate that is within the spawning material range for all species present. The proposed mix includes 26 percent fines, which is consistent with the spawning requirements of Sockeye (WADNR, 2004; Kondolf and Wolman, 1993; and USDA, 2001).

Figure 63: Conceptual layout of habitat complexity (downstream end)

Figure 64: Conceptual layout of habitat complexity (upstream end)

In light of recent research (Tian et al., 2021) regarding the acute toxicity of tire compound 6PPD specifically on coho salmon, water quality should be considered in addition to physical habitat. Given the use of Unnamed Tributary to Tibbetts Creek by coho salmon and the ADT of roadways in the vicinity, benefit to coho salmon cannot be optimized without the construction of Vegetated Filter Strips, Media Filter Drains, or similar along roadways impacted by the project and replacement of existing ditches with Continuous Inflow Biofiltration Swale (or continuous inflow compost amended bioswale (CICABS)) or other stormwater treatment configurations (WSDOT, 2019).

Additionally, there is a high likelihood that African clawed frogs are present within this basin. This invasive, predatory species that can breed year-round. They have been identified in the stormwater pond on mainstem Tibbetts along SR 900 and north of this project site in the parking area for the shopping plaza that includes CostCo. Additional measures may need to be taken during fish exclusion, construction water placement, and dewatering to ensure that if this species is encountered it is contained in accordance with WAC 220-640.

5.2.2 *Stability Analysis*

Stability analysis will be completed in a later phase of the project. However, stability of LWM during overflow events should be carefully considered given downstream infrastructure.

6 Floodplain Changes

Effective FEMA panel 53033C0691J (dated 8/19/20) shows upstream of the project site that during flood events, flow can overtop the left bank of Issaquah Creek, just upstream of NW Gilman Boulevard, and flow along the “Gilman Boulevard Overflow” toward the project site. Though the FEMA maps show an abrupt end of the floodplain mapping at a “Limit of Study” boundary, the direction of those flows can be anticipated by following topography and doing so indicates that Issaquah Creek overtopping flows could reach the project site. Therefore a SRH-2D model was developed to simulate the flow paths from tthe Gilman Boulevard study limit downstream, including the subject crossing site, to where it meets Tibbetts Creek and these estimated flows used in the design of the structure.

There are mapped Base Flood Elevations on the Gilman Boulevard Overflow, upstream of the study limits, however the area is excluded from the floodway (the floodway boundaries are set near the left and right banks of Issaquah Creek). The project crossing, if it were included in the FEMA mapping, would therefore be out of a FEMA floodway and thus a FEMA no-rise analysis not be required. However, SRH-2D simulations indicate that the proposed design for the subject crossing, in addition to the other proposed WSDOT culvert replacements along this flow path, will alter the split of the 100-year overflow coming from Issaquah Creek. Therefore, as part of the FHD stage for this project, updating the FEMA study by extending the mapped floodplain from the study limits of the Gillman Boulevard Overflow downstream to Tibbetts Creek should be considered.

6.1 Floodplain Storage

The proposed condition adds additional floodplain storage by increasing connectivity with downstream reaches and allowing overflow to pass north of I-90, which is currently a restriction during overflow events. Events even up to the 500-year overflow are contained within the flood prone width downstream of the crossing. However, the private crossing (WDFW ID: 920196) may not be able to convey overflow events and create a backwater scenario which may impact infrastructure north of I-90. Additionally, the 500-year overflow event is not contained within the channel upstream of the crossing. Approximately 60 cfs still exit the system along Gilman Boulevard to the west, with potential infrastructure impacts to the south and west.

6.2 Water Surface Elevations

The assessment of changes in WSE, from the existing to the post-project proposed conditions, was evaluated from the SRH-2D model simulations of the 100-year peak flow (see Section 4.5). Figure 65 shows that the proposed conditions significantly reduce the water surface elevation upstream of the project. However, the 100-year overflow event with the proposed condition does increase the water surface elevation downstream of the crossing because of the increased conveyance. This is a significant potential downstream impact and should be considered with local stakeholders.

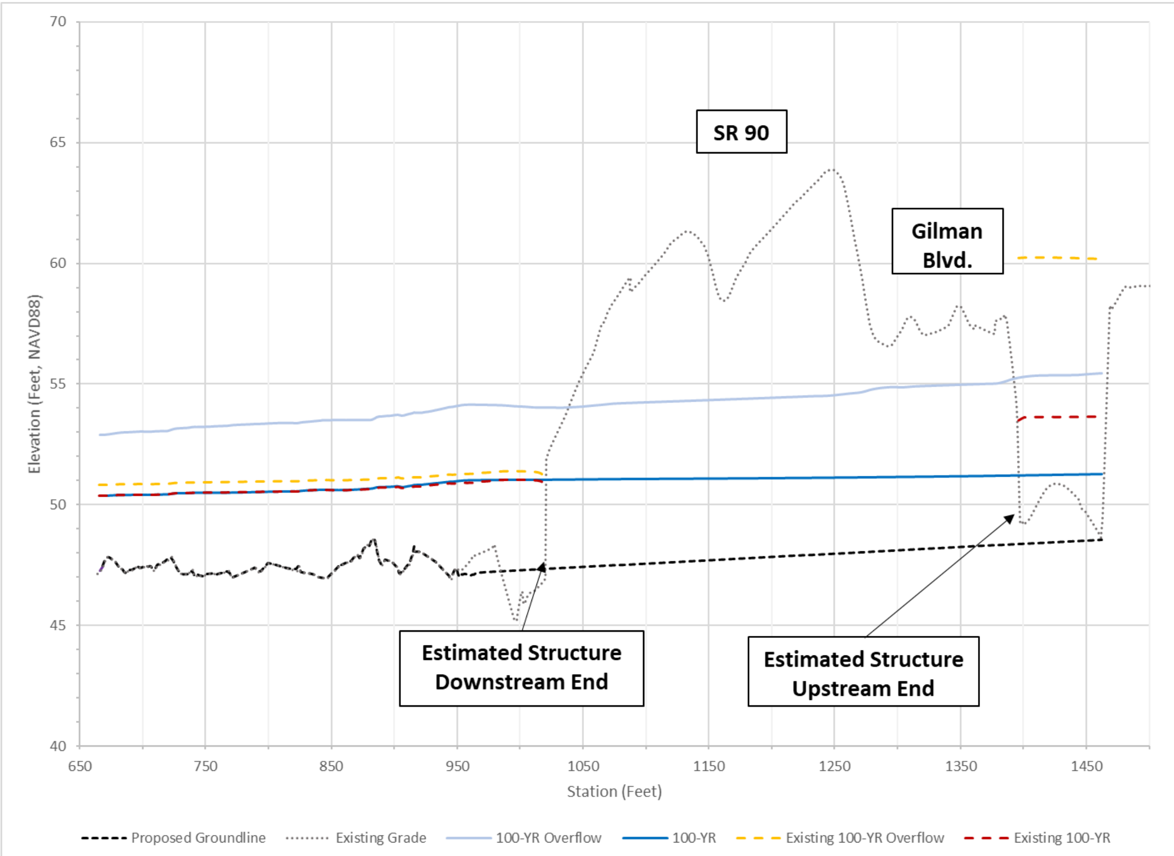

Figure 65: Comparison of proposed and existing conditions for the 100-year and 100-year overflow event

7 Climate Resilience

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. For bridges and buried structures, the largest risk to the structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and maintain passibility for all expected life stages and species in a system.

7.1 Climate Resilience Tools

WSDOT also evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the 2080 percent increase throughout the design of the structure. Appendix J - WDFW Future Projections for Climate-Adapted Culvert Design contains the information received from WDFW for this site.

7.2 Hydrology

For each design, WSDOT uses the best available science for assessing site hydrology. The predicted flows are analyzed in the hydraulic model and compared to field and survey indicators, maintenance history, and any other available information. Hydraulic engineering judgment is used to compare model results to system characteristics; if there is significant variation, then the hydrology is re-evaluated to determine whether or not adjustments need to be made, including adding standard error to the regression equation, basin changes in size or use, etc.

In addition to using the best available science for current site hydrology, WSDOT is evaluating the structure at the 2080 predicted 100-year flow event to check for climate resiliency. The Design Flow for the crossing is 73 cfs at the 100-year storm event. The projected increase for the 2080 flow rate is 36.4 percent, yielding a projected 2080 flow rate of 100 cfs. However, considering that flows from the Gilman Boulevard Overflow are significantly higher, designing the structure resilience to these overflows inherently encompasses the climate resilience flows. This study does not take into account predicted 2080 flows of the Gilman Boulevard Overflow, future flow projection of Issaquah Creek is likely to include stakeholder involvement in future phases.

7.3 Climate Resilience Summary

A minimum hydraulic opening of 17 feet and a minimum freeboard of three feet allows for the channel to behave similarly through the structure as it does in the adjacent reaches under the projected 2080 100-year flow event. This will help ensure that the structure is resilient to climate change and the system is allowed to function naturally, including the passage of sediment, debris, and water in the future.

8 Scour Analysis

Total Scour will be computed during later phases of the project utilizing the 100-year, 500-year, and projected 2080 100-year flow events as well as 50-, 100-, and 500-year Gilman Boulevard Overflow events. The structure will be designed to account for the potential scour at the 100-year overflow event, given that it is greater than the projected 2080 100-year flow events. For this phase of the project, the risk for lateral migration and potential for degradation are evaluated on a conceptual level. This information is considered preliminary and is not to be taken as a final recommendation in either case.

8.1 Lateral Migration

Lateral migration risk at this crossing is considered low due to the moderately confined nature of the channel and the adjacent development (Section 2.8.5).

8.2 Long-term Aggradation/Degradation of the River Bed

Section 2.8.4 indicates a long-term aggradation potential of up to one foot; however, sediment deposited from an Gilman Boulevard Overflow event may result in higher aggradation. Long-term degradation is estimated to be one to two feet, due to the low channel slope, proximity to equilibrium, and sediment observed. However, scour from n Gilman Boulevard Overflow event is likely greater than long-term degradation.

Summary

Table 25: Report Summary Table

Stream Crossing Category	Elements	Values	Report Location
Habitat Gain	Total Length	2,713 ft.	1 Introduction
Bankfull Width	Average BFW	9.0 ft.	2.8.2 Channel Geometry
	Reference reach found?	Y	2.8.1 Reference Reach Selection
Channel Slope/Gradient	Existing Crossing	0.56%	2.8.4 Vertical Channel Stability
	Reference Reach	0.45%	2.8.2 Channel Geometry
	Proposed	0.30%	4.3.2 Channel Planform and Shape
Countersink	Proposed	3 ft.	4.6.3 Freeboard
	Added for climate resiliency	0	4.6.3 Freeboard
Scour	Analysis	See Link	8 Scour Analysis
	Streambank protection/stabilization	See Link	8 Scour Analysis
Channel Geometry	Existing	See Link	2.8.2 Channel Geometry
	Proposed	See Link	4.3.2 Channel Planform and Shape
Floodplain Continuity	FEMA mapped floodplain	N	6 Floodplain Changes
	Lateral Migration	N	2.8.5 Channel Migration
	Floodplain changes?	Y	6 Floodplain Changes
Freeboard	Required Above 100 yr	2 ft.	4.6.3 Freeboard
	Added for climate resiliency	0	4.6.3 Freeboard
	Additional Recommended	1 ft.	4.6.3 Freeboard
Maintenance Clearance	Proposed	6 ft.	4.6.3 Freeboard
Substrate	Existing	See Link	2.8.3 Sediment
	Proposed	See Link	5.1 Bed Material
Hydraulic Opening	Proposed	17 ft.	4.6.2 Minimum Hydraulic Opening Width and Length
	Added for climate resiliency	N	4.6.2 Minimum Hydraulic Opening Width and Length
Channel Complexity	LWM	Y	5.2 Channel Complexity
	Meander Bars	Y	5.2 Channel Complexity
	Boulder Clusters	N	5.2 Channel Complexity
	Mobile Wood	N	5.2 Channel Complexity
Crossing length	Existing	376 ft.	2.7.2 Existing Conditions
	Proposed	376 ft.	4.6.2 Minimum Hydraulic Opening Width and Length
Floodplain Utilization Ratio (FUR)	Floodprone Width	23.6 ft.	4.2 Existing Conditions Model Results
	Average FUR Upstream and DS	2.6 ft.	4.2 Existing Conditions Model Results
Hydrology/Design Flows	Existing	See Link	3 Hydrology and Peak Flow Estimates
	Climate resiliency	See Link	3 Hydrology and Peak Flow Estimates
Channel Morphology	Existing	See Link	2.8.2 Channel Geometry
	Proposed	See Link	5.2 Channel Complexity
Channel Degradation	Potential?	Y	8.2 Long-term Aggradation/Degradation of the River Bed
	Allowed?	Y	8.2 Long-term Aggradation/Degradation of the River Bed
Structure Type	Recommendation	N	4.6.1 Structure Type
	Type	N/A	4.6.1 Structure Type

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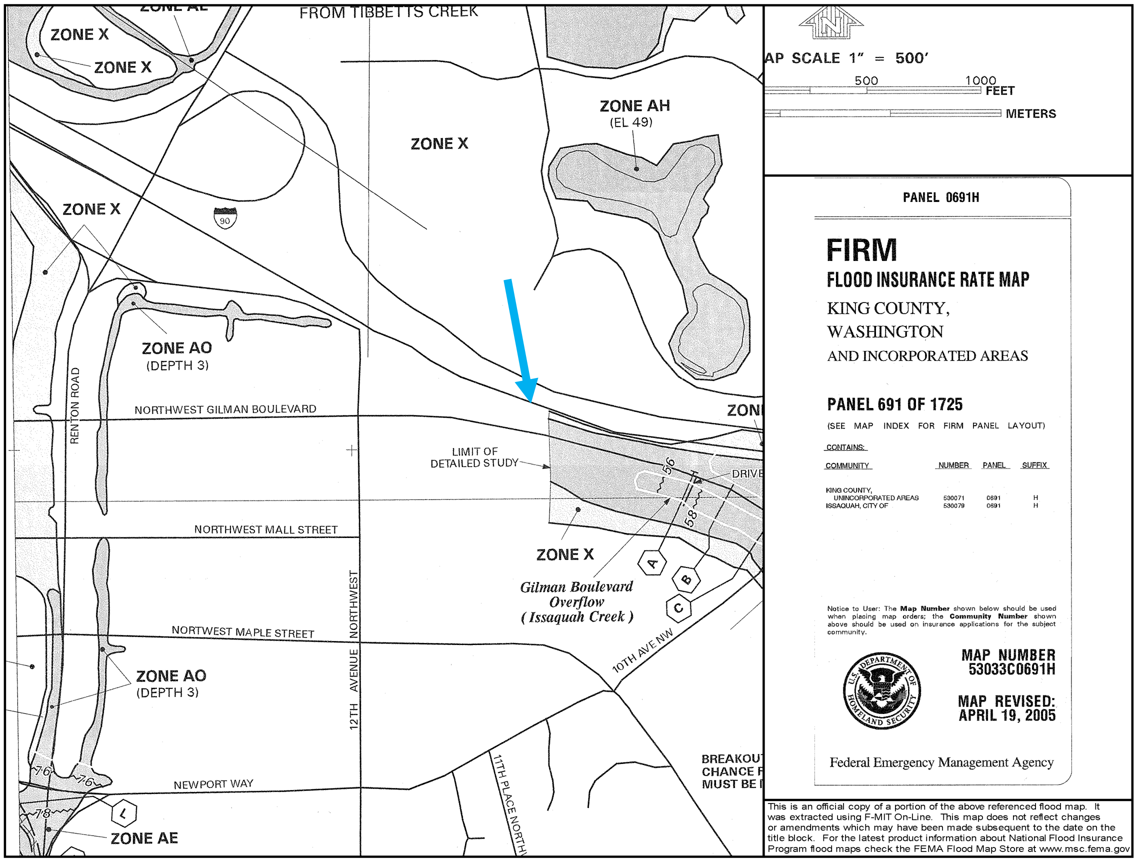
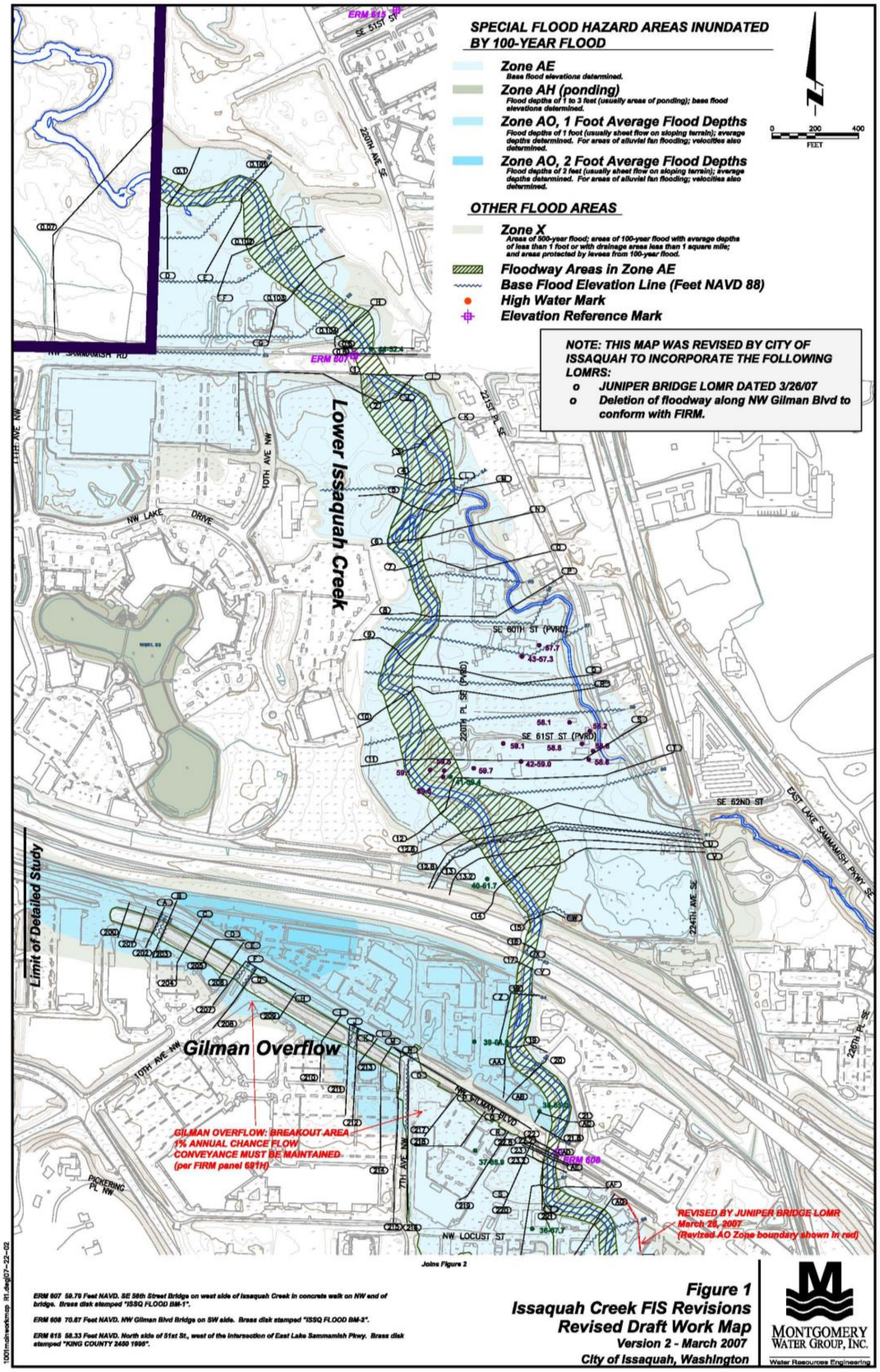
Appendices

Appendix A - FEMA Floodplain Map



FEMA Effective FIRM. Blue arrow shows approximate crossing location



FEMA Workmap showing details of Gilman Overflow. Project site is a located short distance west of where this map ends.

Appendix B - Hydraulic Field Report Form

WSDOT Hydraulics Section	Hydraulics Field Report	Project Number:
	Project Name: WSDOT King Co. Culvert Replacements	Date: 05/14/2020
	Project Office: Northwest Hydraulic Consultants	Time of Arrival: 12:00
	Location: Unnamed Tributary to Tibbetts Creek at I-90 MP 16.21	Time of Departure: 16:00
Purpose of Visit:	Weather: Partly cloudy	Prepared By: Annie Dufficy (NHC)

Meeting Location:
Taco Time NW (1125 NW Gilman Blvd)

Attendance List:

Name	Organization	Role
Annie Dufficy	Northwest Hydraulic Consultants	Geomorphologist
Tyler Rockhill	Northwest Hydraulic Consultants	Hydraulic Engineer
Alex Anderson	Northwest Hydraulic Consultants	Hydraulic Engineer

Bankfull Width:

**Blue flagging was labeled and tied to vegetation on the channel banks for all BFW measurements*

*BFW 1 was measured behind Big Lots (beige brick part of the building) in a channel bend glide over a small boulder in the channel (*Figure B-66*). Measured BFW was 8 feet. This location is 200 feet downstream of the I-90 culvert.*

Figure B-66 BFW 1

*BFW 2 was measured at the southwestern corner of the Big Lots building in a long glide with reed canary grass on both banks (*Figure B-67*). Measured BFW was 9 feet. This location is 300 feet downstream of I-90.*

Figure B-67 BFW 2

*BFW 3 was measured behind PetSmart about 40 feet downstream of the Girken Ski shop (you can see the awning of the ski shop in the photo below (*Figure B-68*). This was measured in the reference reach in a wood-forced riffle downstream of a notched log weir. Measured BFW was 9.5 feet.*

Figure B-68 BFW 3

Reference Reach:

The reference reach includes the partially restored stream segment downstream of the I-90 crossing starting about 200 feet downstream of the crossing and extending downstream just before the steep riffle reach 150 feet upstream of the city culvert (WDFW Culvert ID 920196). This is also commonly known as the 12th Avenue restored reach of Pickering Creek by the Lake Sammamish Kokanee Working Group. The stream maintains an average slope of about 0.45% through the reach, which is fairly consistent with the slopes observed throughout the crossing vicinity. Large wood additions to the stream include log weirs and logs anchored to the stream banks, DBH of about 1 to 2 feet. This wood has added hydraulic complexity by encouraging upstream sediment deposition of coarse sands and gravels and downstream scour pools, resulting in wood-forced riffle-pool sequences. The channel has established some sinuosity in this restored reach. NHC measured meander sinuosity of 1.07, defined as the ratio of the channel length to the corridor length. Bankfull width varies from 8 to 10 feet in the reach. Starting 200 feet downstream of the I-90 crossing the reach transitions from grass-dominated banks to a dense woody canopy. In this segment, channel banks are locally shallower.

Figure B-69 View looking downstream of the reference reach at a notched-weir-forced riffle

Data Collection:

Three people from NHC were involved in conducting the field survey of the northern Unnamed Tributary to Tibbetts Creek, where staff collected BFW measurements, pebble counts, and noted general observations about the reach extending from the culvert inlet of WDFW Culvert 920193 to the city culvert downstream (WDFW Culvert 920196), a reach of about 4000 feet.

Observations:

The northern Unnamed Tributary to Tibbetts Creek in the vicinity of the I-90 MP 16.21 crossing is a channelized stream. Under existing conditions, the tributary is constrained laterally within a narrow urban corridor. Downstream of the crossing the channel is entrenched 2 to 3 feet below a vegetated bench. The beds and banks are composed of mostly clay and organic material, but previous large wood restoration work downstream of the crossing has introduced channel complexity in the form of riffle-pool sequences and alluvial bed deposits in the wood-forced riffles. At the time of the survey, the culvert inlet was mostly clear of sediment and debris, apart from pervasive ivy growth in the area (Figure B-70). The wetted channel width was about 4 feet upstream of the culvert inlet and no backwater was observed. Conditions change downstream as NHC observed a deep scour pool at the culvert outlet with existing water levels filling the 15-foot wide wingwall area up to about half of the culvert's height.

Figure B-70 Existing conditions at the I-90 culvert inlet (left) and outlet (right) (blue arrows show flow direction)

NHC walked 400 feet upstream of the I-90 MP 16.21 culvert observing stream and riparian conditions across the two culvert crossings immediately upstream (Figure B-71). The channel is mostly straight flowing through a narrow 60-ft corridor bound on either side by concrete parking lots of the commercial shopping area. The channel is only about 5-ft wide upstream, bound by steep overbank slopes densely vegetated with shurbs. Closer to the I-90 culvert inlet the riparian area is occupied by English ivy and some trees that have introduced wood into the stream. Although constrained laterally, the narrow channel has established some minor sinuosity and exhibits glide morphology. Wood-forced riffles are present in the reach between WDFW Culvert ID 920194 and the I-90 culvert inlet. NHC conducted a pebble count on this bed in order to characterize the approximate bedload composition available to the reach downstream of I-90.

Figure B-71 Conditions upstream of the WDFW Culvert ID 920194 (left) and upstream the I-90 project culvert (right) (blue arrows show flow direction)

Channel shape and morphology change downstream of I-90 (Figure B-72). The stream is restricted within the 100-ft wide corridor bound between I-90 eastbound on the left bank and commercial property (Big Lots, Girken Ski Shop, and PetSmart) on the right bank. The channel widens to the full width of the wingwalls at the culvert outlet and then narrows to 4 to 8 feet for the first 100 feet downstream. Below this BFW widens with the addition of LWM to a width of 8 to 10 feet. The channel is entrenched about 2 to 3 feet below a vegetated channel bench that accommodates higher flows. The bed and banks are composed of cohesive clay but coarse gravel beds were observed in glide and riffle reaches influenced by LWM. Large wood has been added to the stream, both anchored along banks, and functioning as log weirs further downstream. All notable riffle-pool sequences are wood-forced. The riparian area within the first 200 feet of the culvert outlet is restricted to mostly reed canary grass and blackberry, but transitions into a dense canopy of mature trees downstream, adding natural wood to the channel in addition to the engineered logs.


Figure B-72 Conditions 100 feet downstream of I-90 behind Big Lots (left) and a view of the partially restored channel located behind PetSmart 400 feet downstream of I-90 (right) (blue arrows show flow direction)

Describe location of sediment sampling and pebble counts if available

NHC conducted Wolman pebble counts in three riffle reaches (one upstream of I-90 and two downstream) and one glide downstream of the I-90 crossing.

The first pebble count was measured in a wood-forced riffle-glide 30 feet upstream of the 1-90 culvert inlet (). This is just downstream of the largest LWM jam upstream of I-90. Channel widths in this reach are only about 5 feet.

Figure B-8 Pebble Count 1 taken 30 feet upstream of I-90 culvert inlet in riffle bed

The second pebble count was measured in a very narrow riffle-glide about 80 feet downstream of the culvert outlet where channel width is only 3 feet wide. This reach is located behind the southeastern corner of the Big Lots building. The gravel was imbricated and armored.

Figure B-9 Pebble Count 2 taken in narrow riffle segment

The third pebble count was conducted in a wood-forced riffle influenced by natural and engineered wood in the reference reach. The bed was armored, protecting fine gravel and sand underneath, which overly the massive clay substrate that bounds the entire downstream reach. This was measured about 10 feet downstream of Pebble Count 2 at the southwestern corner of the Big Lots building.

Figure B-10 Pebble Count 3

The fourth and final pebble count was conducted downstream of a notched-log-weir-forced riffle. The deposit was imbricated and armored, protecting the same fine substrate as observed in Pebble Count 3. This was taken at the same location as BFW 3.

Figure B-11 Pebble Count 4

A few boulders were observed in the field. These are not naturally occurring and likely placed as bank protection. These were observed about 80 feet downstream of the I-90 culvert outlet on the right bank and on the bed at the location of BFW 2.

Figure B-12 Large boulder observed on right bank approximately 80 feet downstream of I-90 culvert outlet

As previously discussed, the entire downstream reach is entrenched inside a cohesive clay deposit. Clay makes up the entire channel banks downstream and provide strength. It is also exposed on the bed downstream in areas where there is less alluvial gravel.

It is believed that a lot of the sediment observed downstream was placed in the 12th Ave restoration project, completed over the past ten years. Plans to this project were not made available to NHC for official review. Regardless, this stream does not have an abundant sediment supply, as observed by it's mostly clay or fine-grained bed.

Figure B-13 Clay exposed on the banks (top) and bed below the I-90 crossing (bottom) (white arrow points to clay)

Appendix C - SRH-2D Model Results

Figure C-38: Proposed Conditions 500-Year Overflow Velocity Near the Proposed Crossing
Figure C-39: Proposed Conditions 500-Year Overflow Depth Near the Proposed Crossing
Figure C-40: Proposed Conditions 500-Year Overflow Shear Stress Near the Proposed Crossing

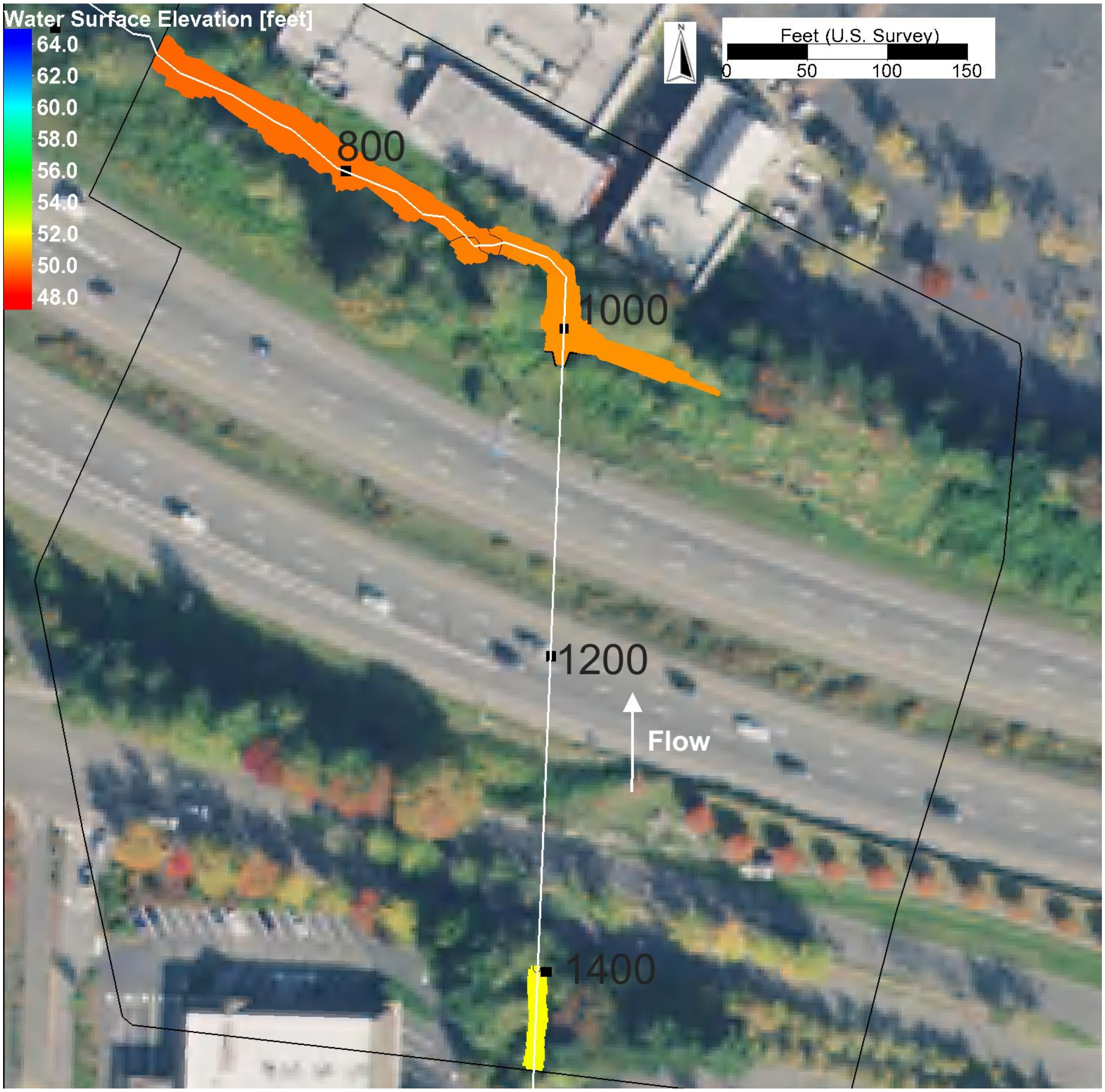


Figure C-1: Existing Conditions 2-Year Water Surface Elevation Near the Existing Crossing

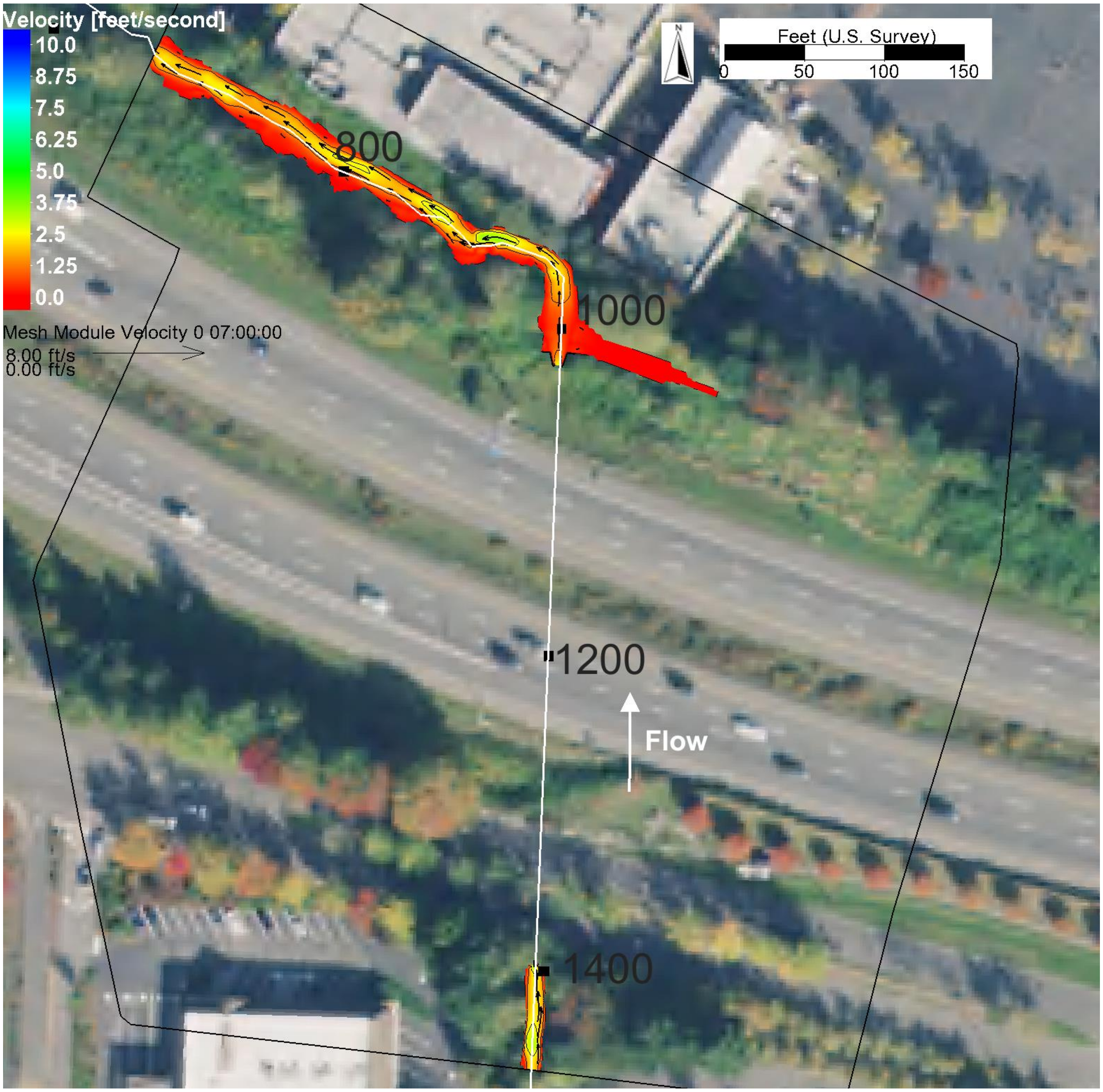


Figure C-2: Existing Conditions 2-Year Velocity Near the Existing Crossing

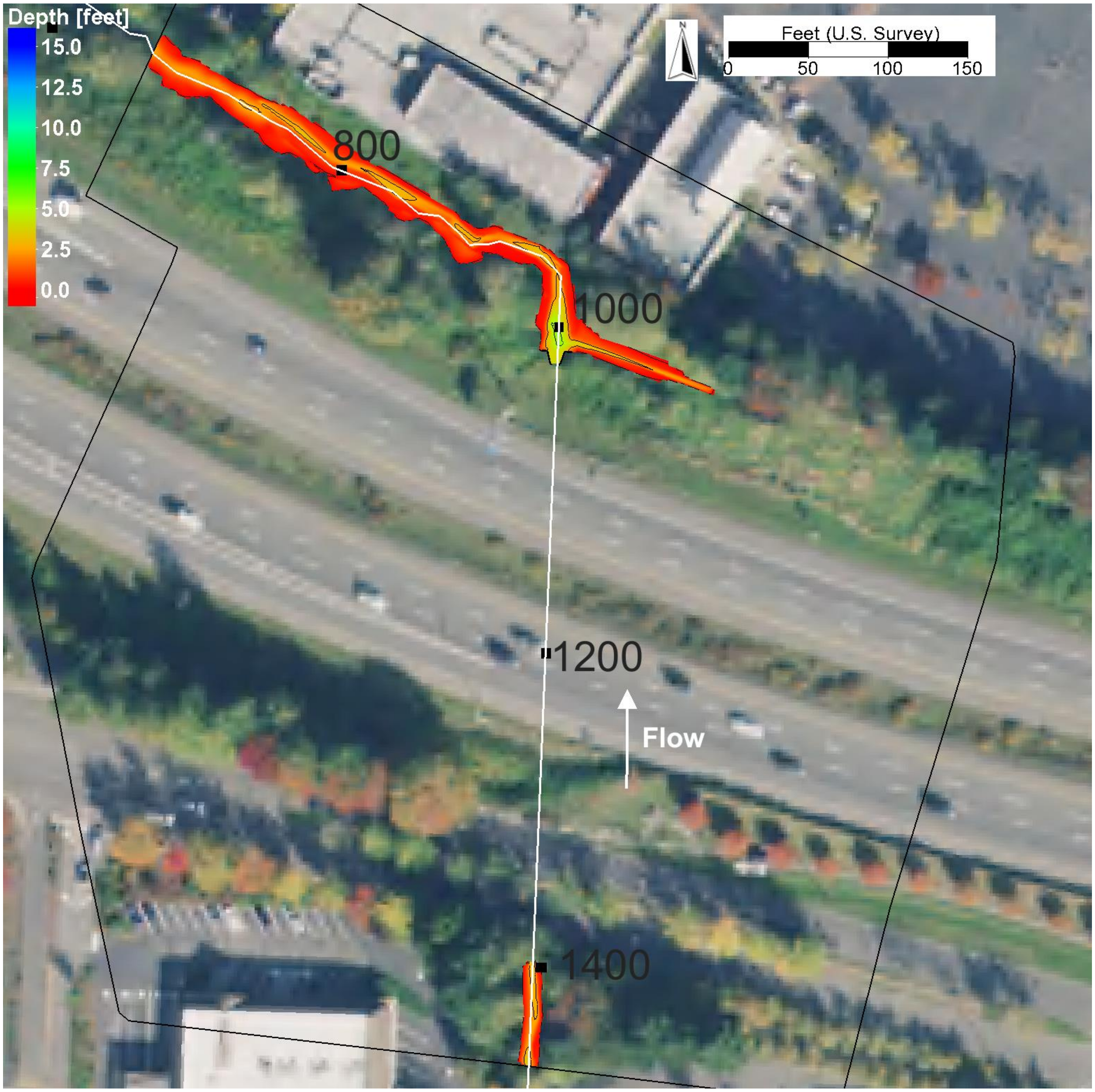


Figure C-3: Existing Conditions 2-Year Depth Near the Existing Crossing

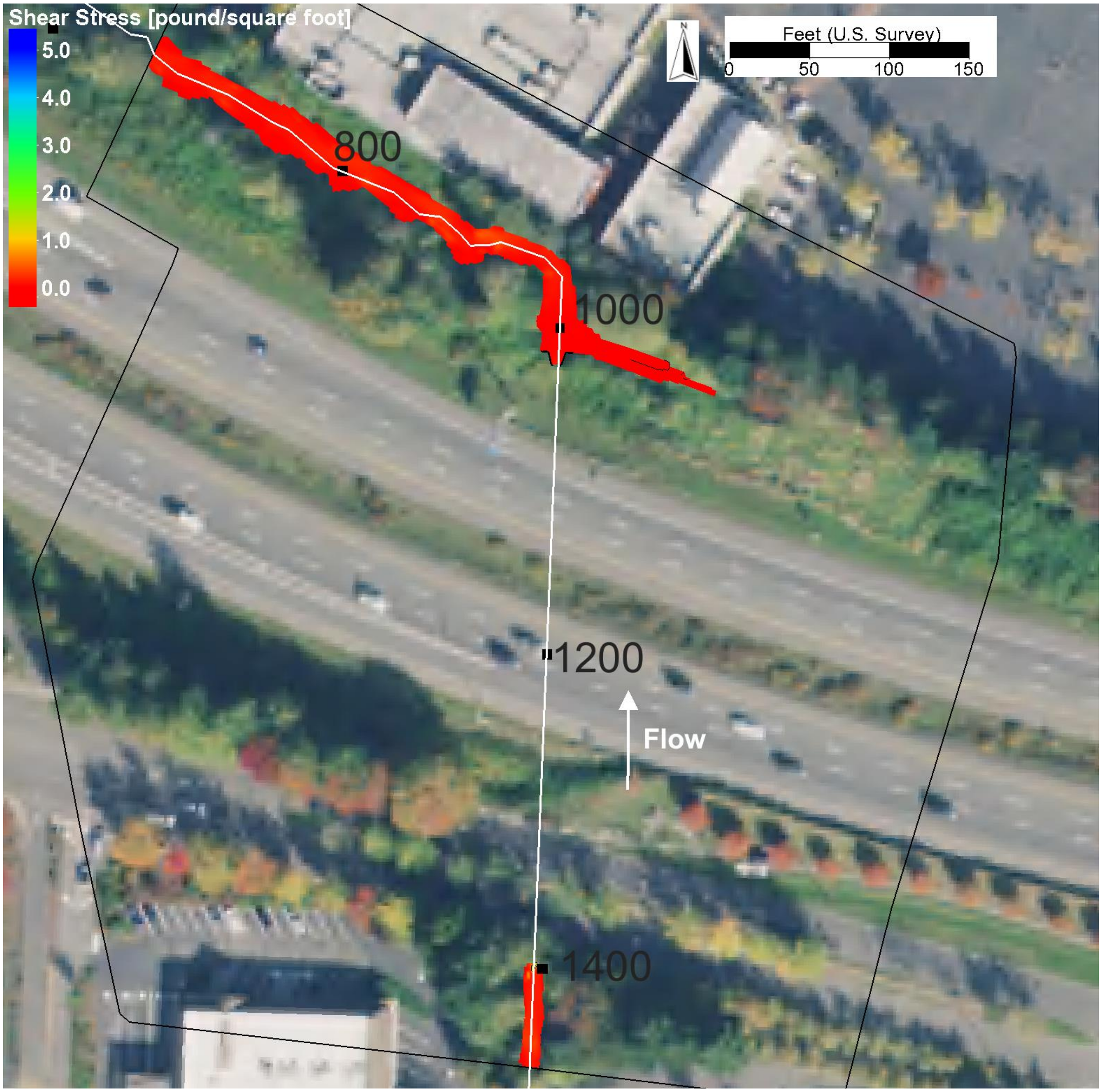


Figure C-4: Existing Conditions 2-Year Shear Stress Near the Existing Crossing

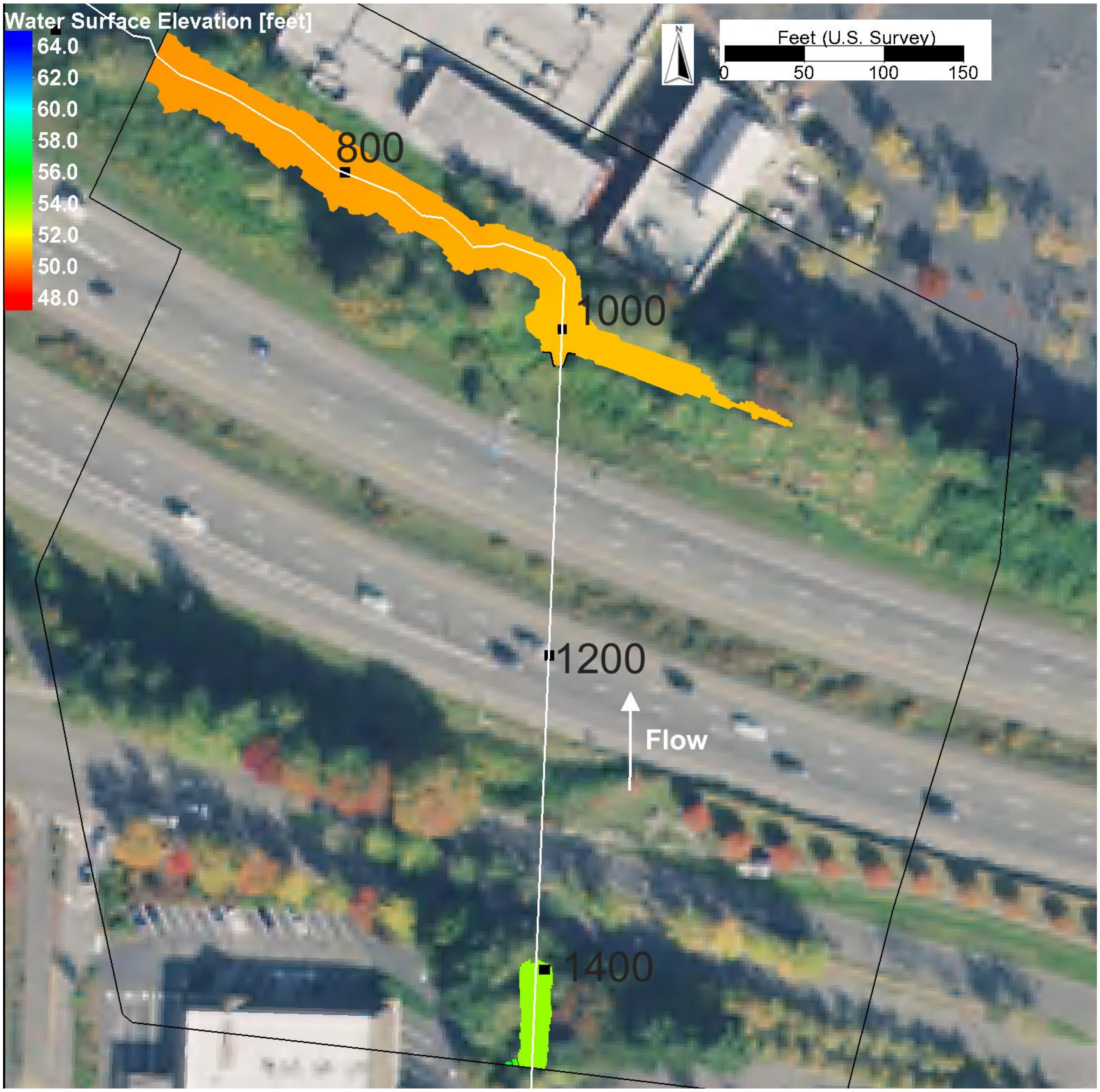


Figure C-5: Existing Conditions 100-Year Water Surface Elevation Near the Existing Crossing

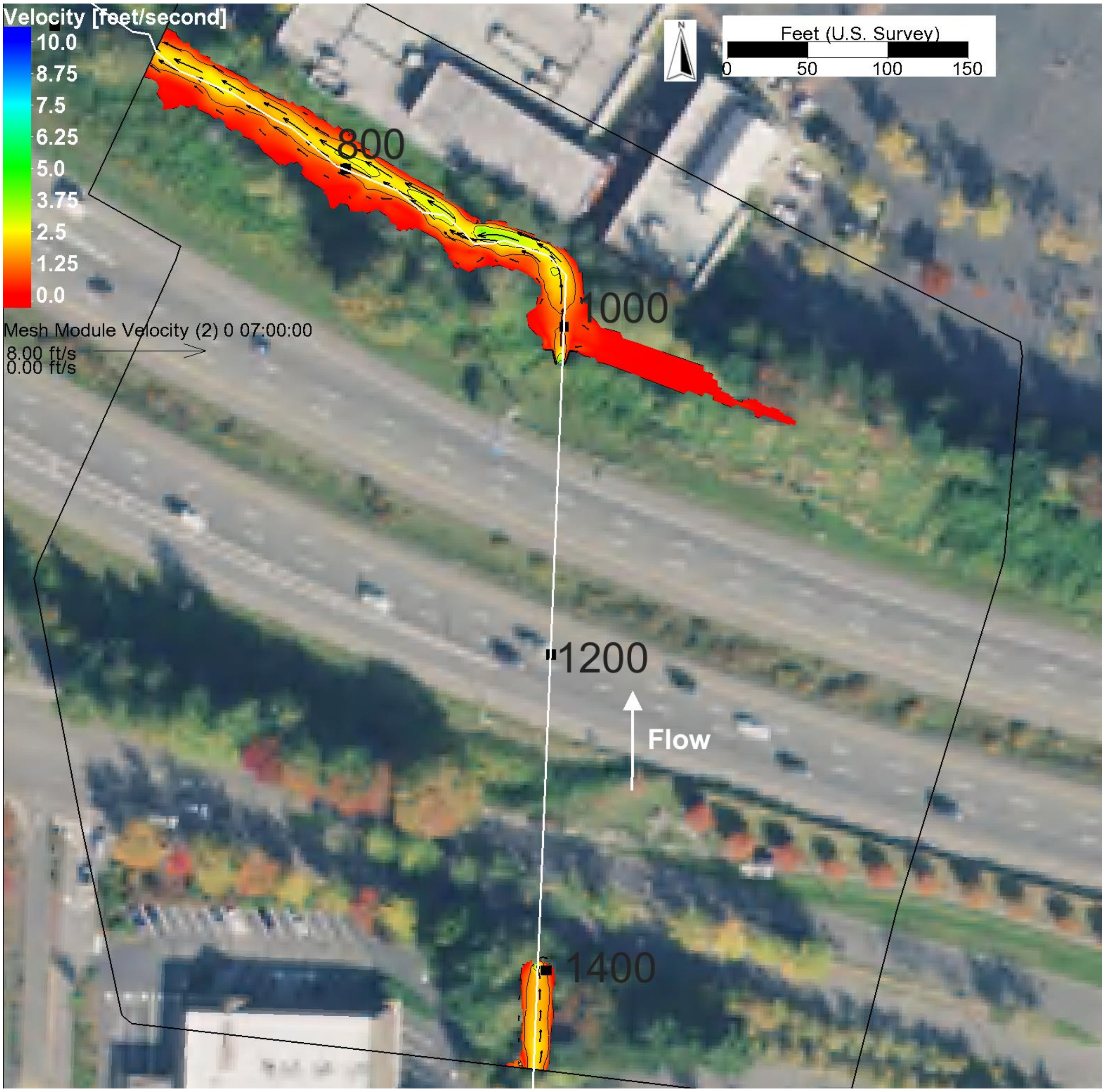


Figure C-6: Existing Conditions 100-Year Velocity Near the Existing Crossing

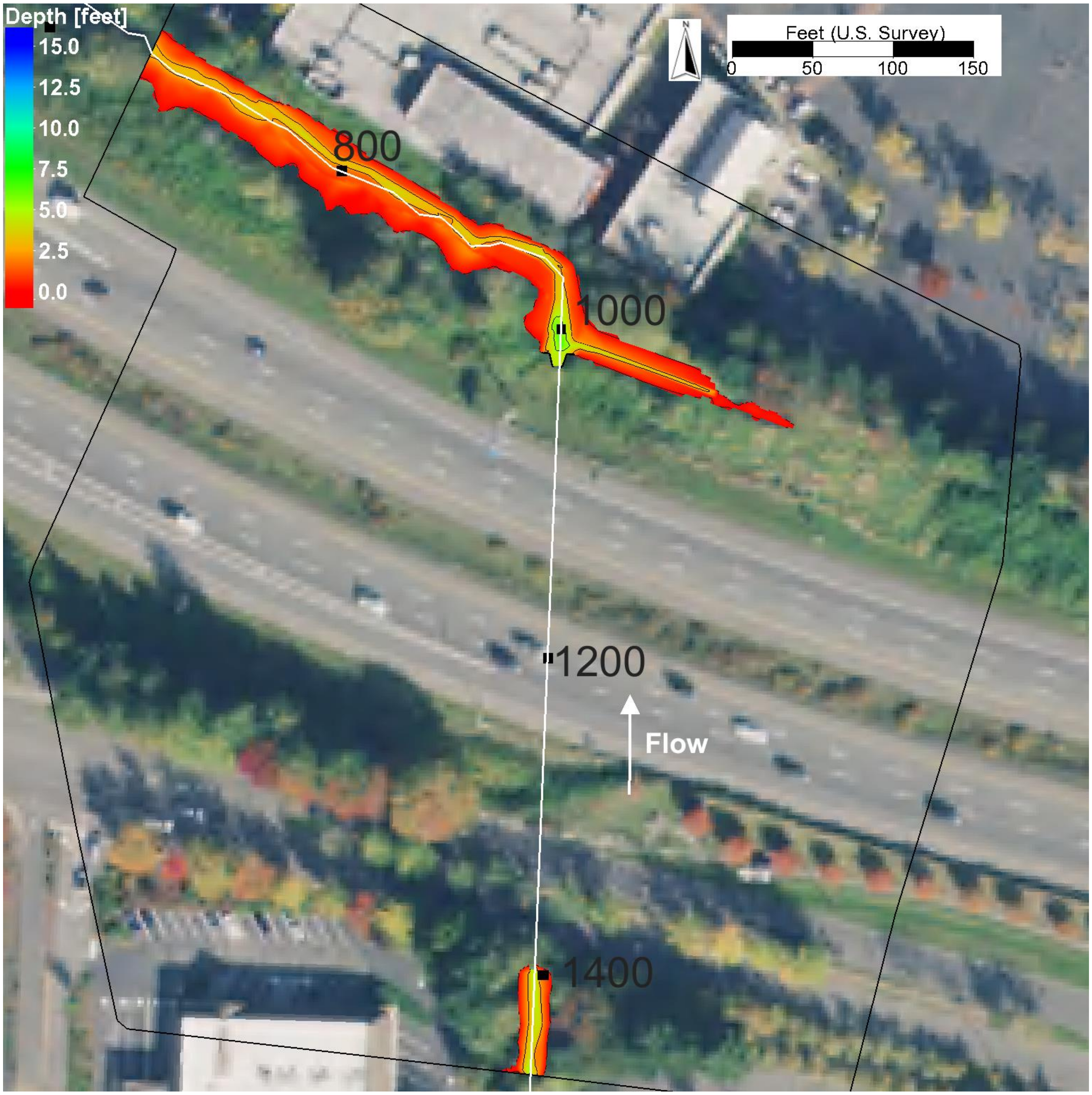


Figure C-7: Existing Conditions 100-Year Depth Near the Existing Crossing

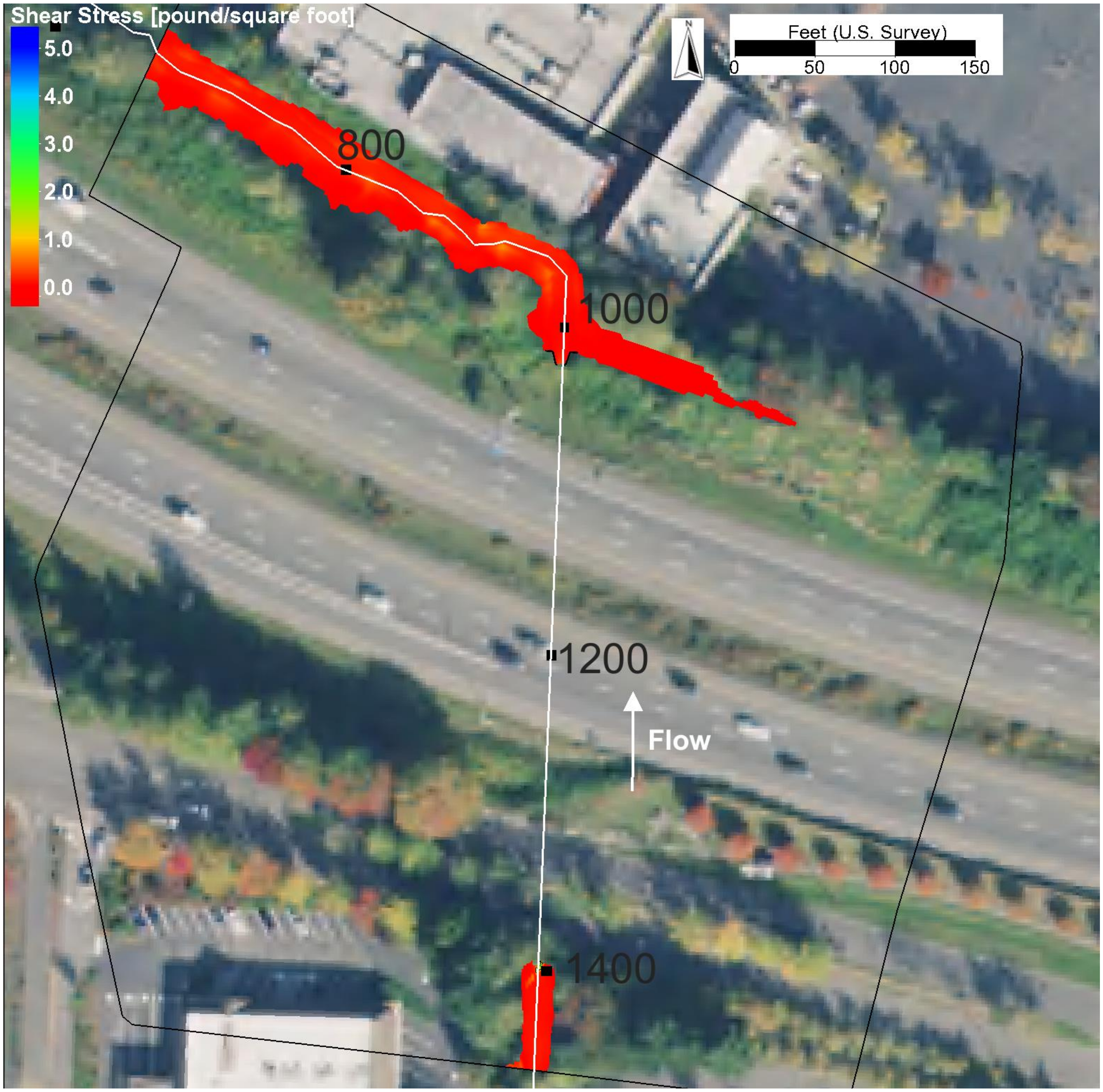


Figure C-8: Existing Conditions 100-Year Shear Stress Near the Existing Crossing

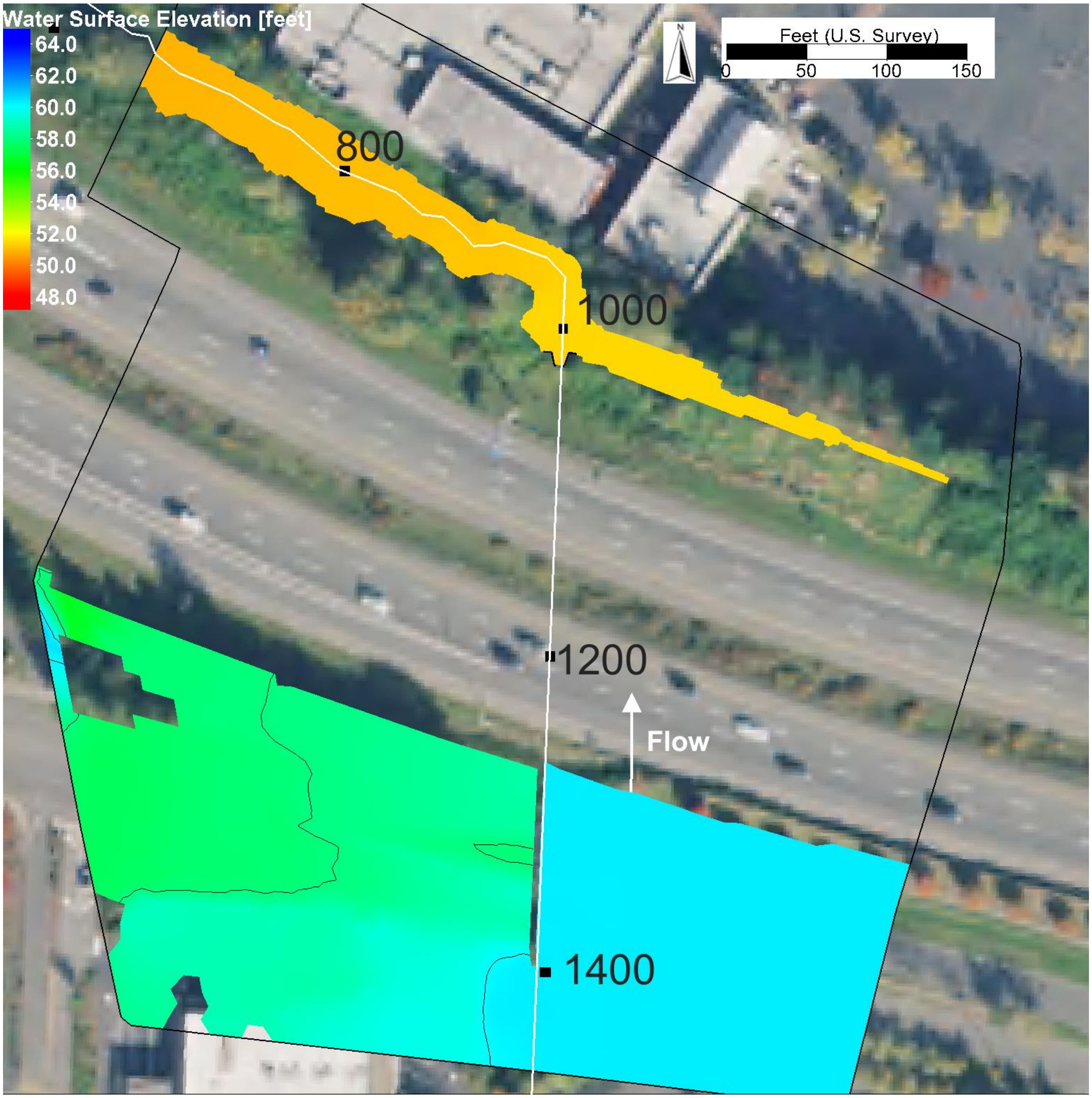


Figure C-9: Existing Conditions 100-Year Overflow Water Surface Elevation Near the Existing Crossing

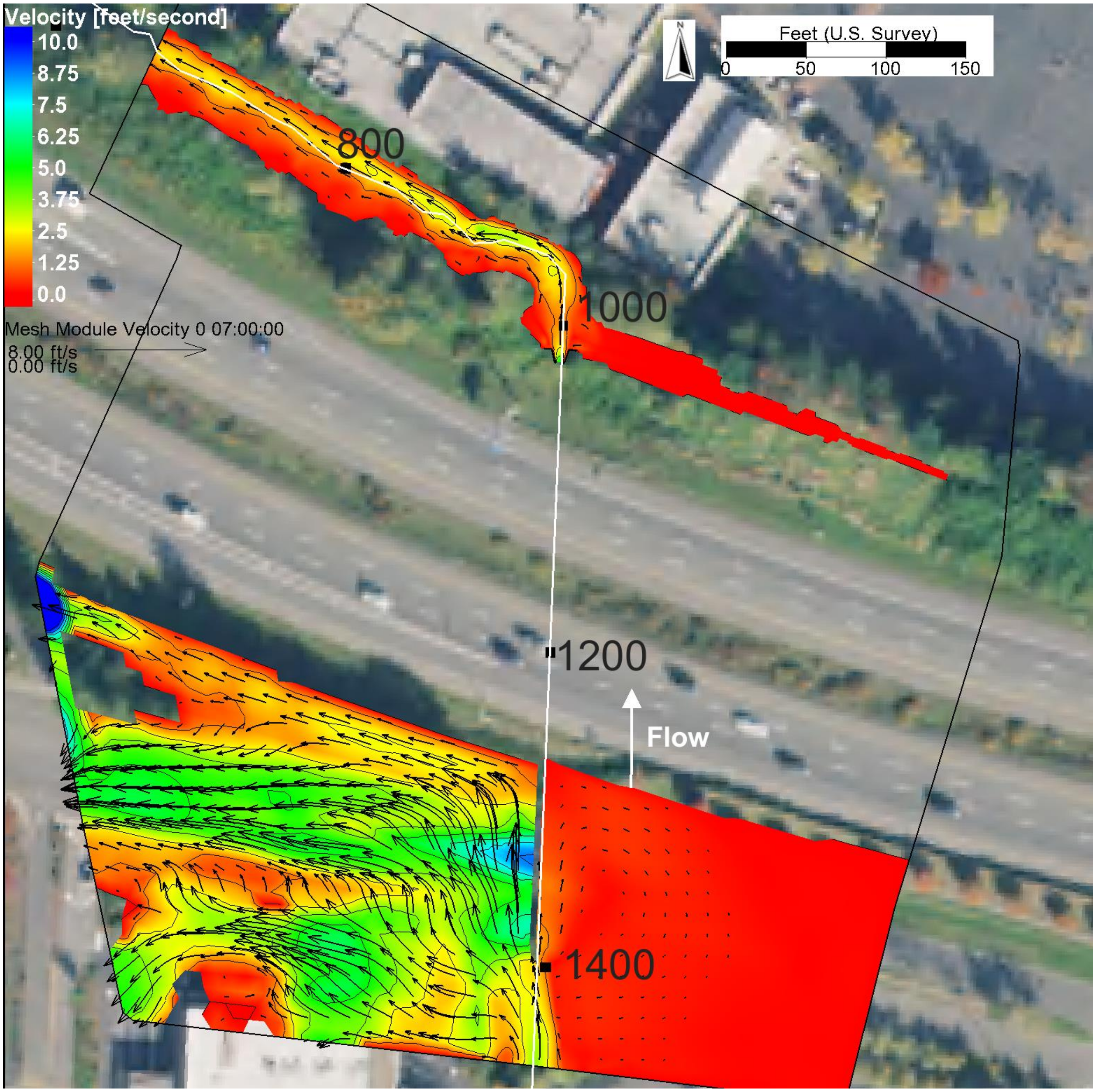


Figure C-10: Existing Conditions 100-Year Overflow Velocity Near the Existing Crossing

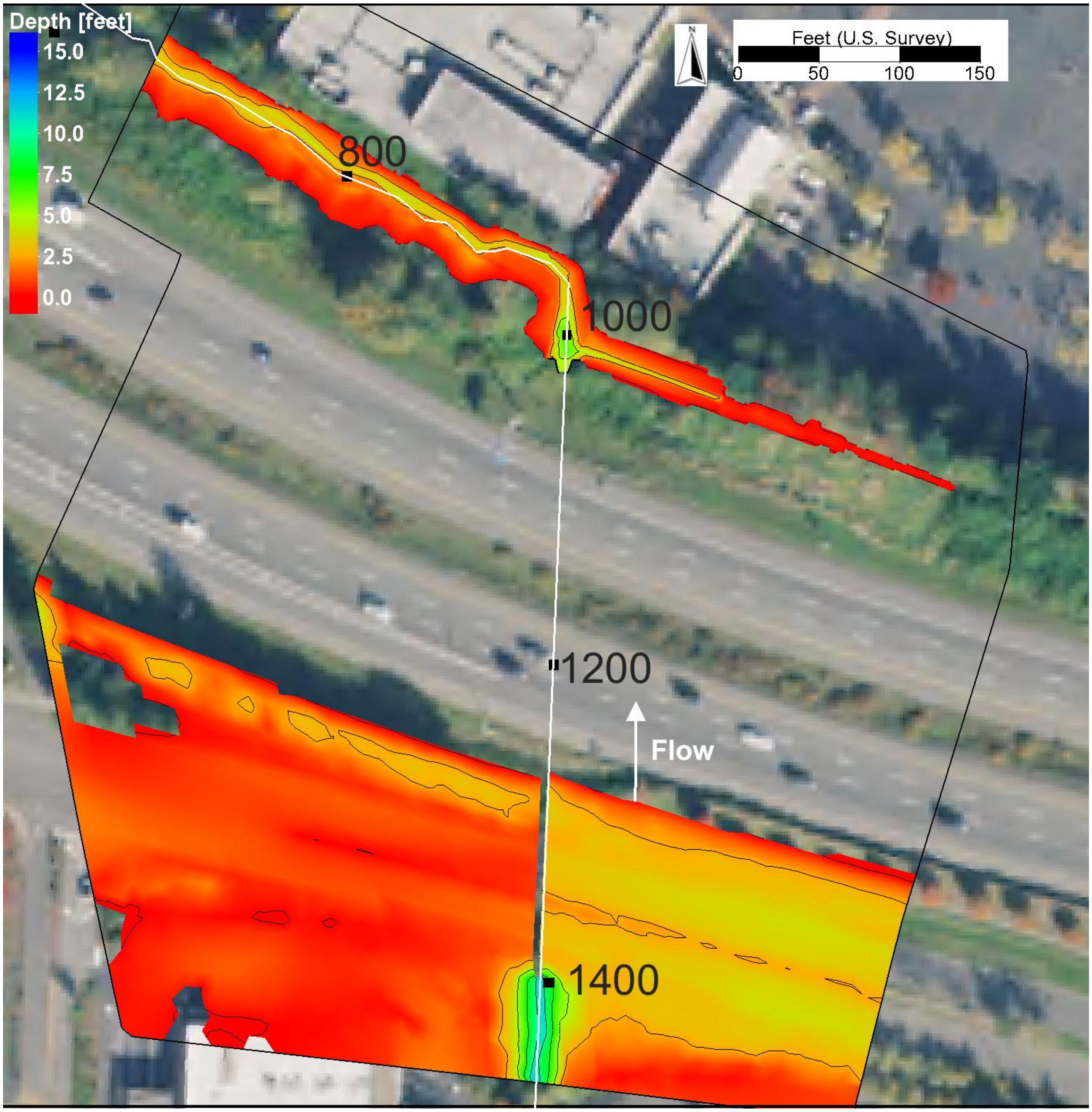


Figure C-11: Existing Conditions 100-Year Overflow Depth Near the Existing Crossing

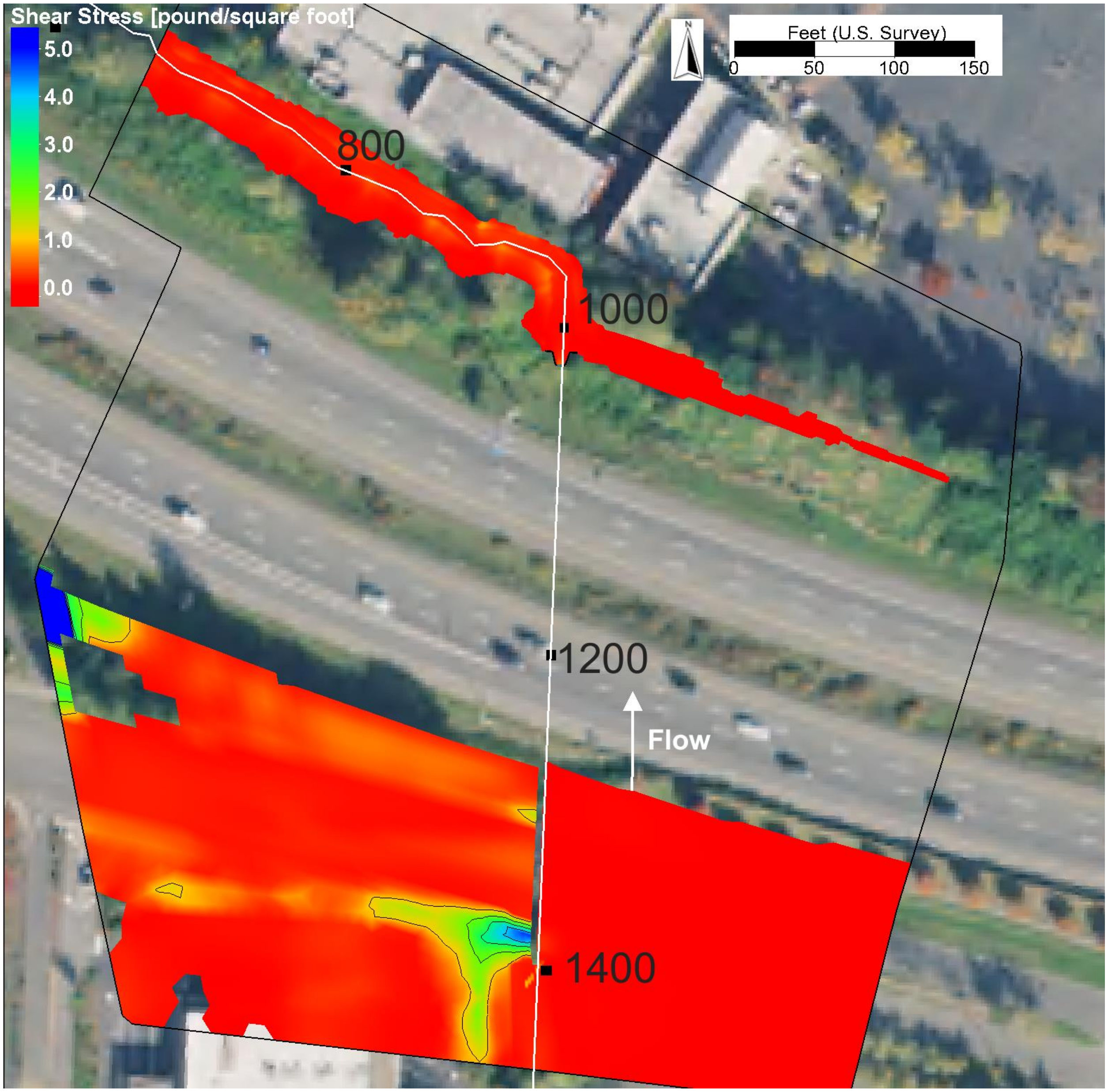


Figure C-12: Existing Conditions 100-Year Overflow Shear Stress Near the Existing Crossing

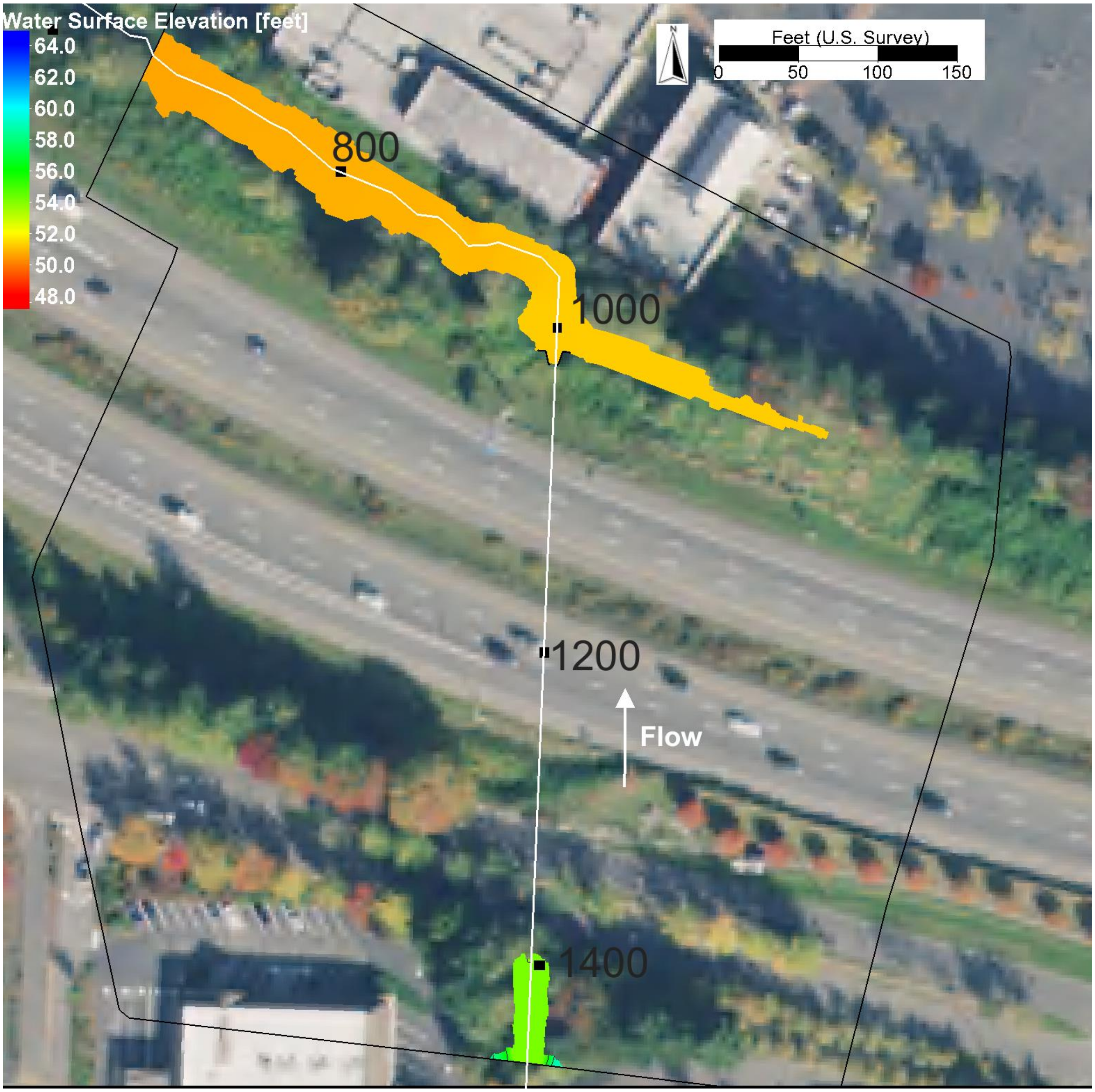


Figure C-13: Existing Conditions 500-Year Water Surface Elevation Near the Existing Crossing

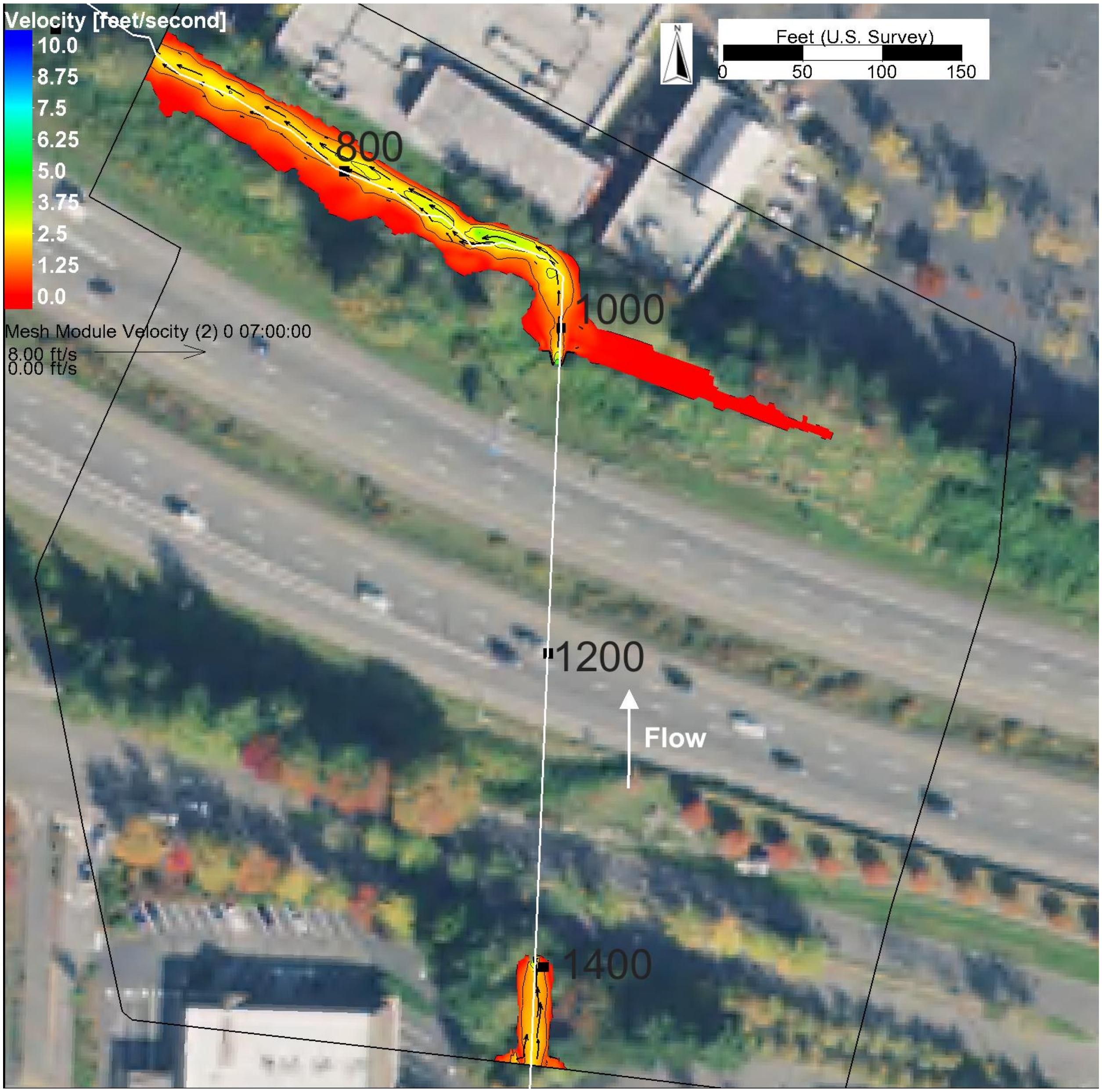


Figure C-14: Existing Conditions 500-Year Velocity Near the Existing Crossing

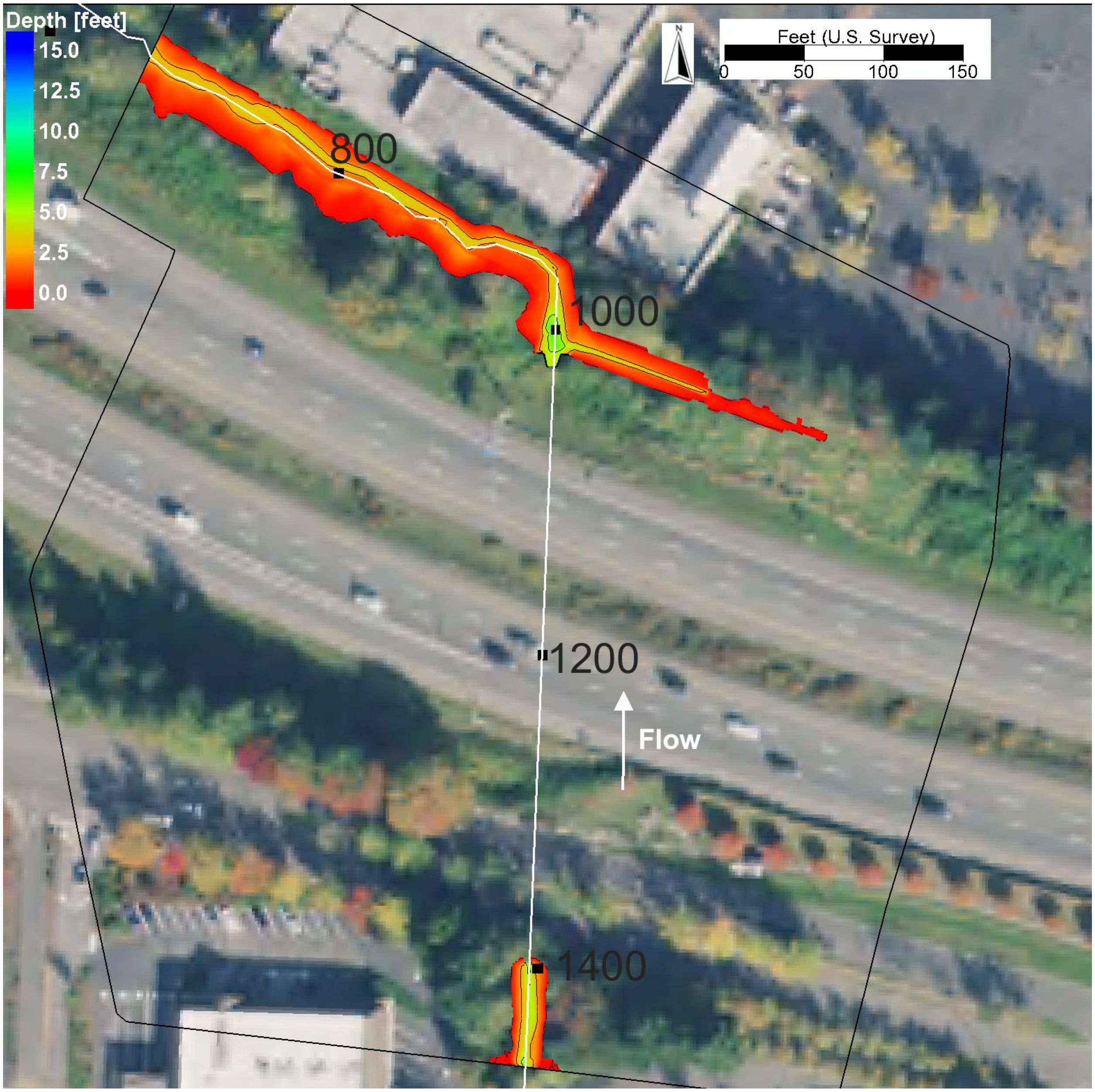


Figure C-15: Existing Conditions 500-Year Depth Near the Existing Crossing

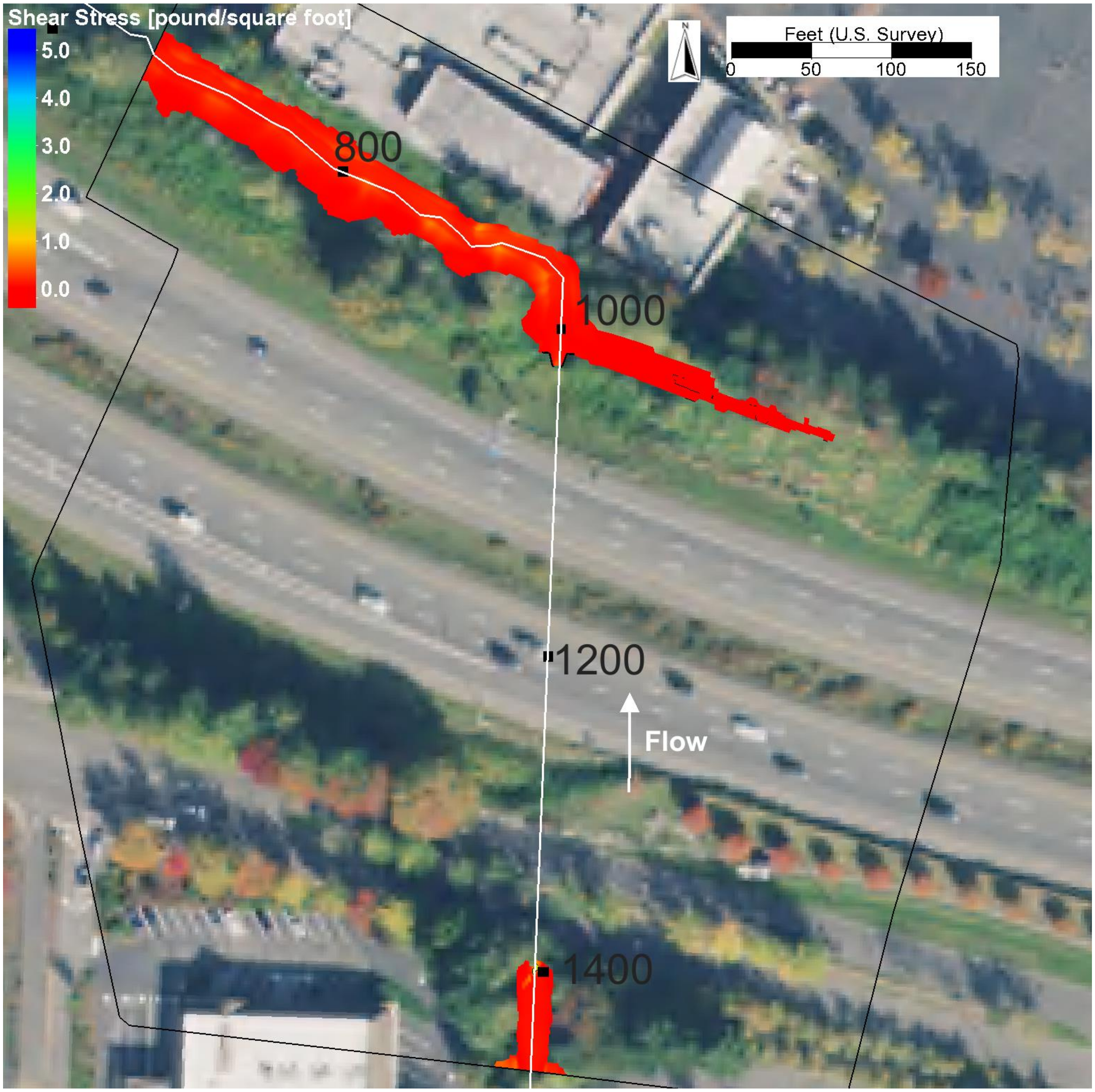


Figure C-16: Existing Conditions 500-Year Shear Stress Near the Existing Crossing

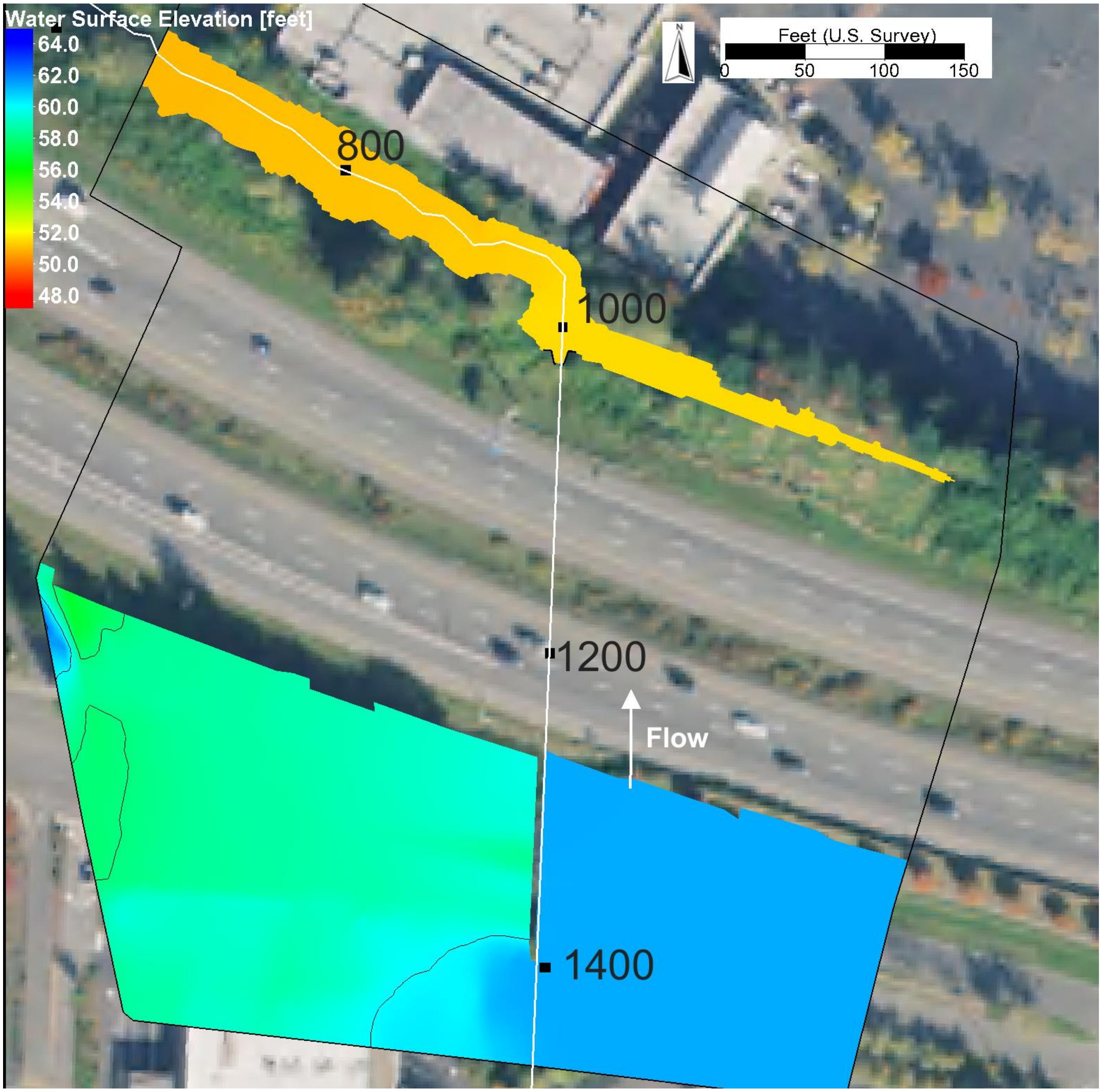


Figure C-17: Existing Conditions 500-Year Overflow Water Surface Elevation Near the Existing Crossing

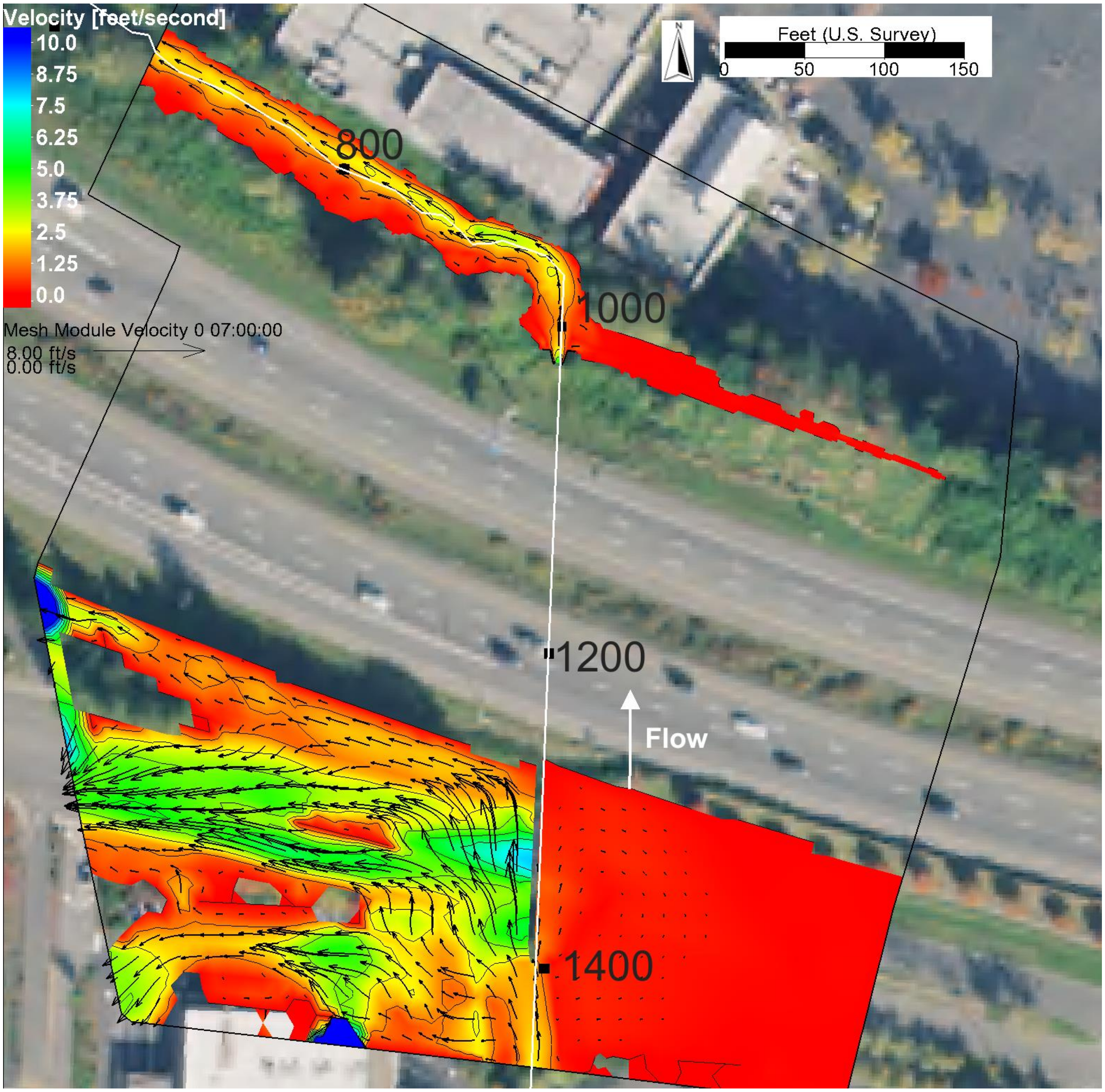


Figure C-18: Existing Conditions 500-Year Overflow Velocity Near the Existing Crossing

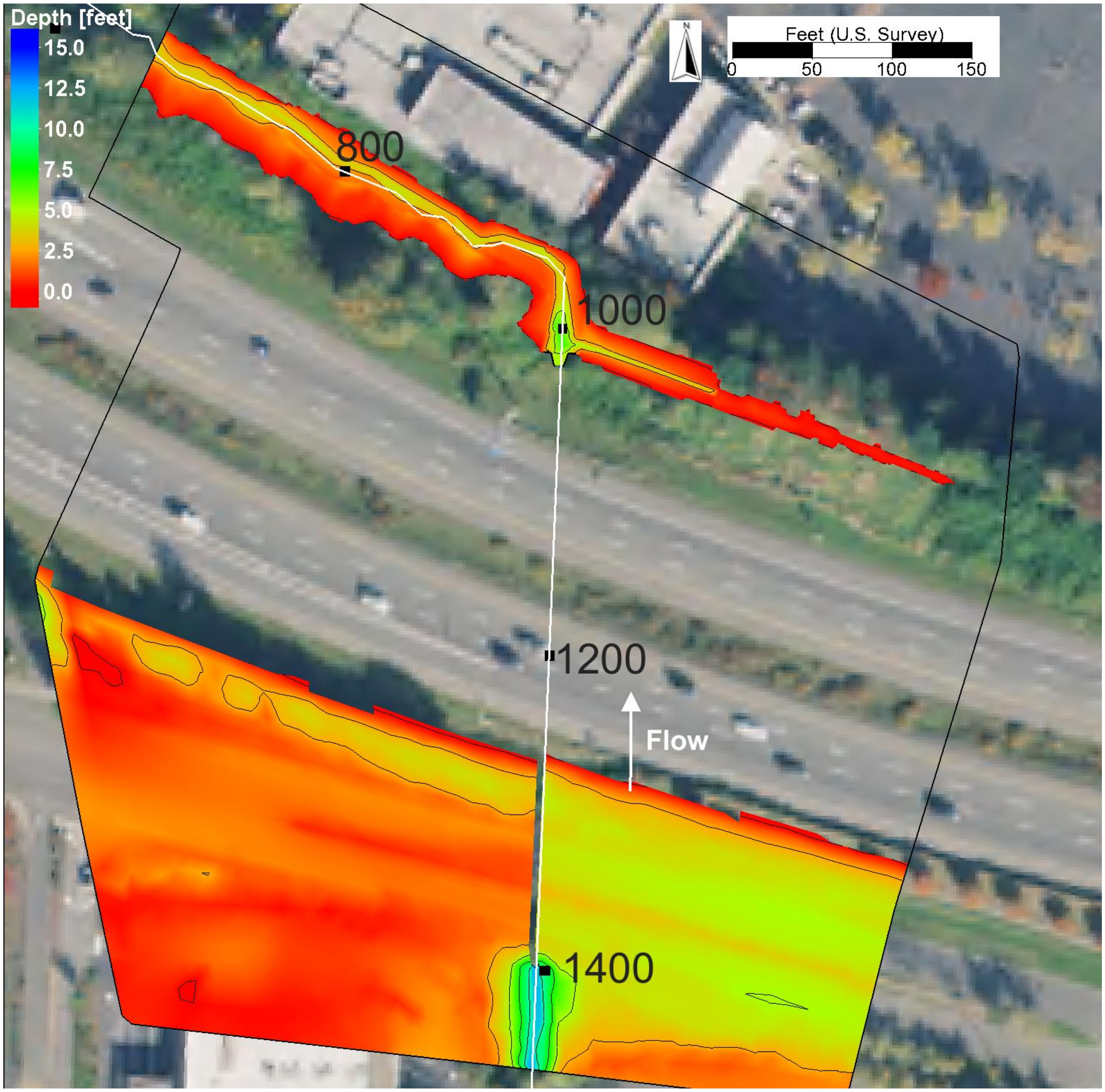


Figure C-19: Existing Conditions 500-Year Overflow Depth Near the Existing Crossing

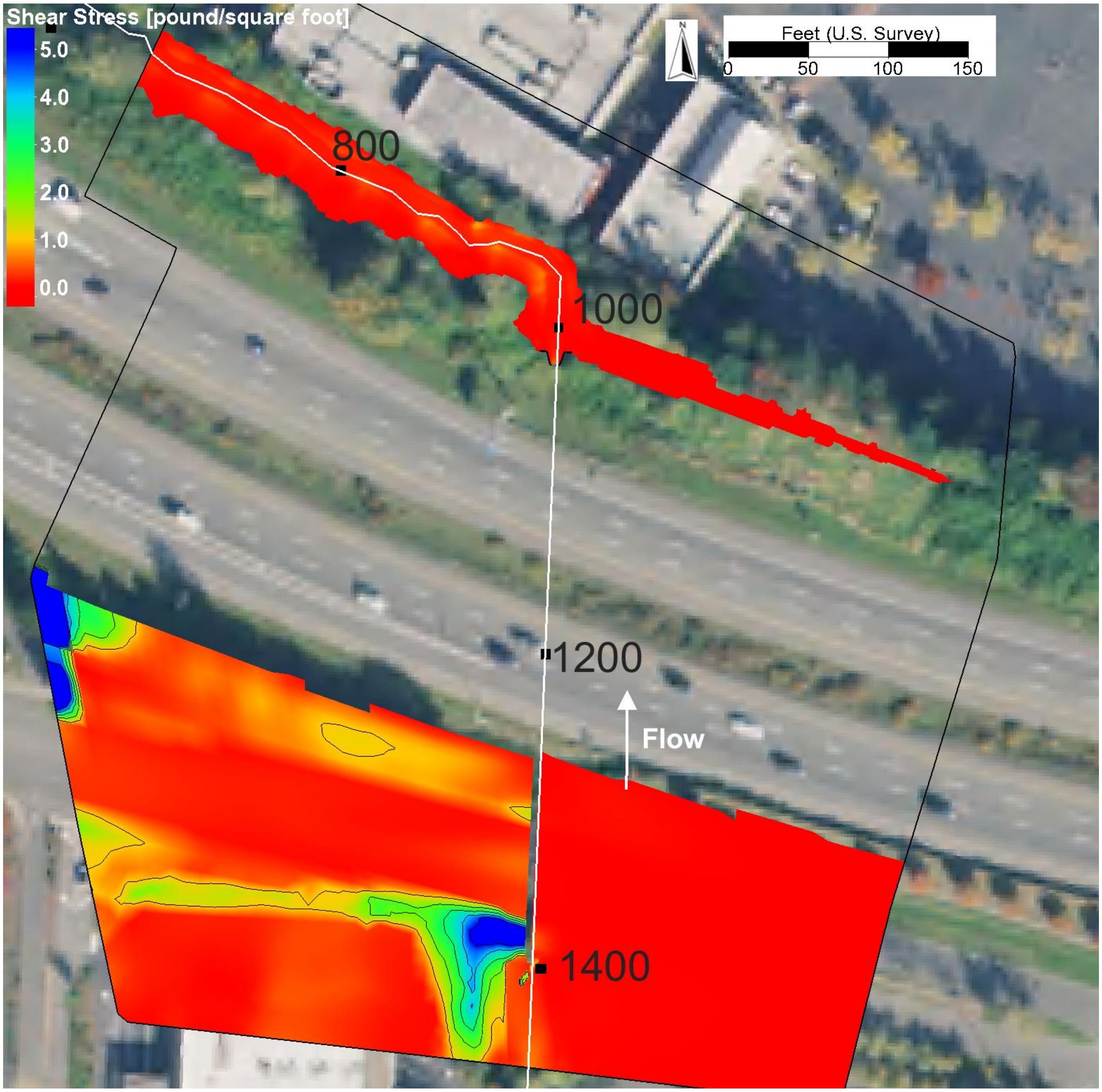


Figure C-20: Existing Conditions 500-Year Overflow Shear Stress Near the Existing Crossing

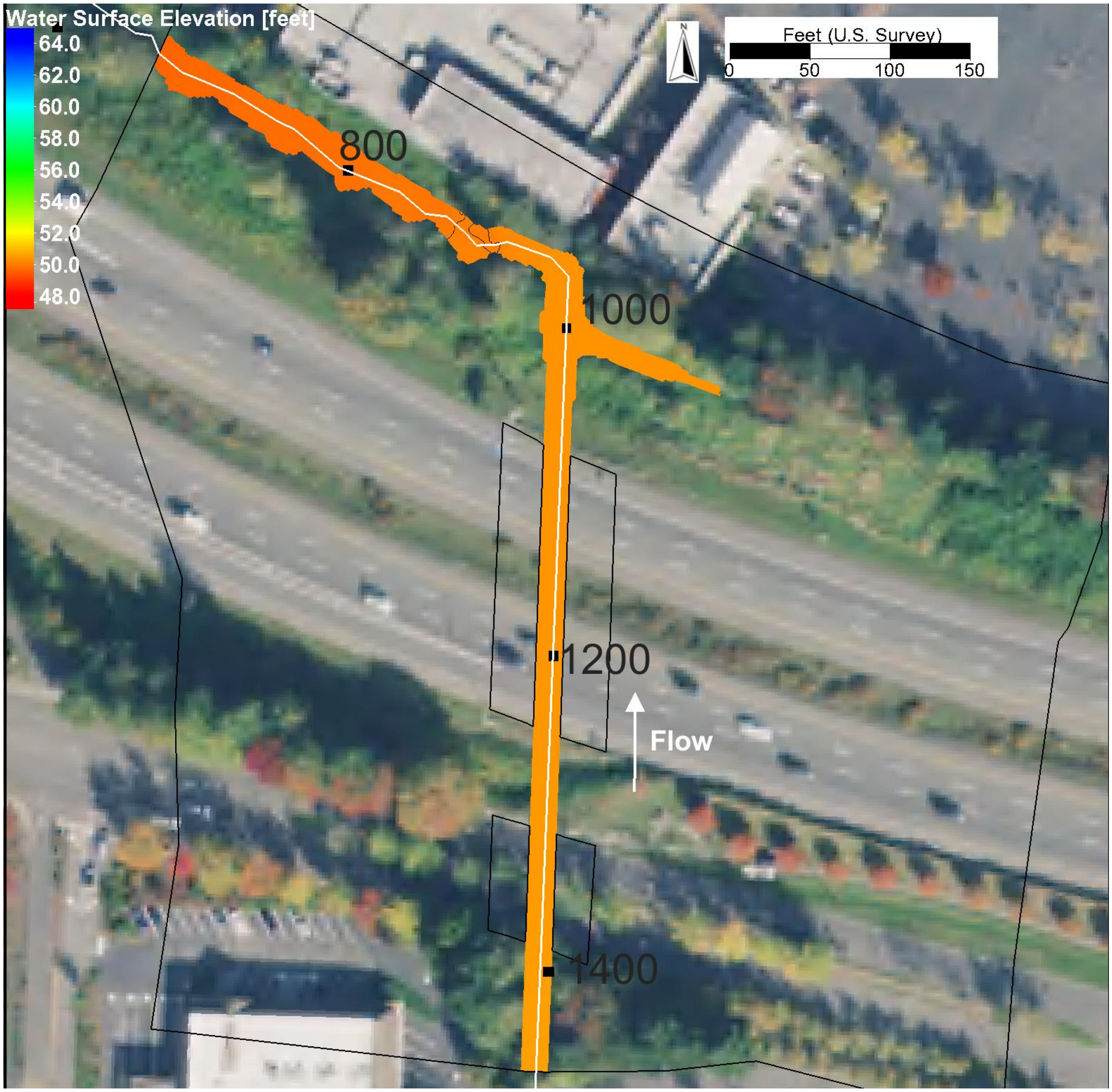


Figure C-21: Proposed Conditions 2-Year Water Surface Elevation Near the Proposed Crossing

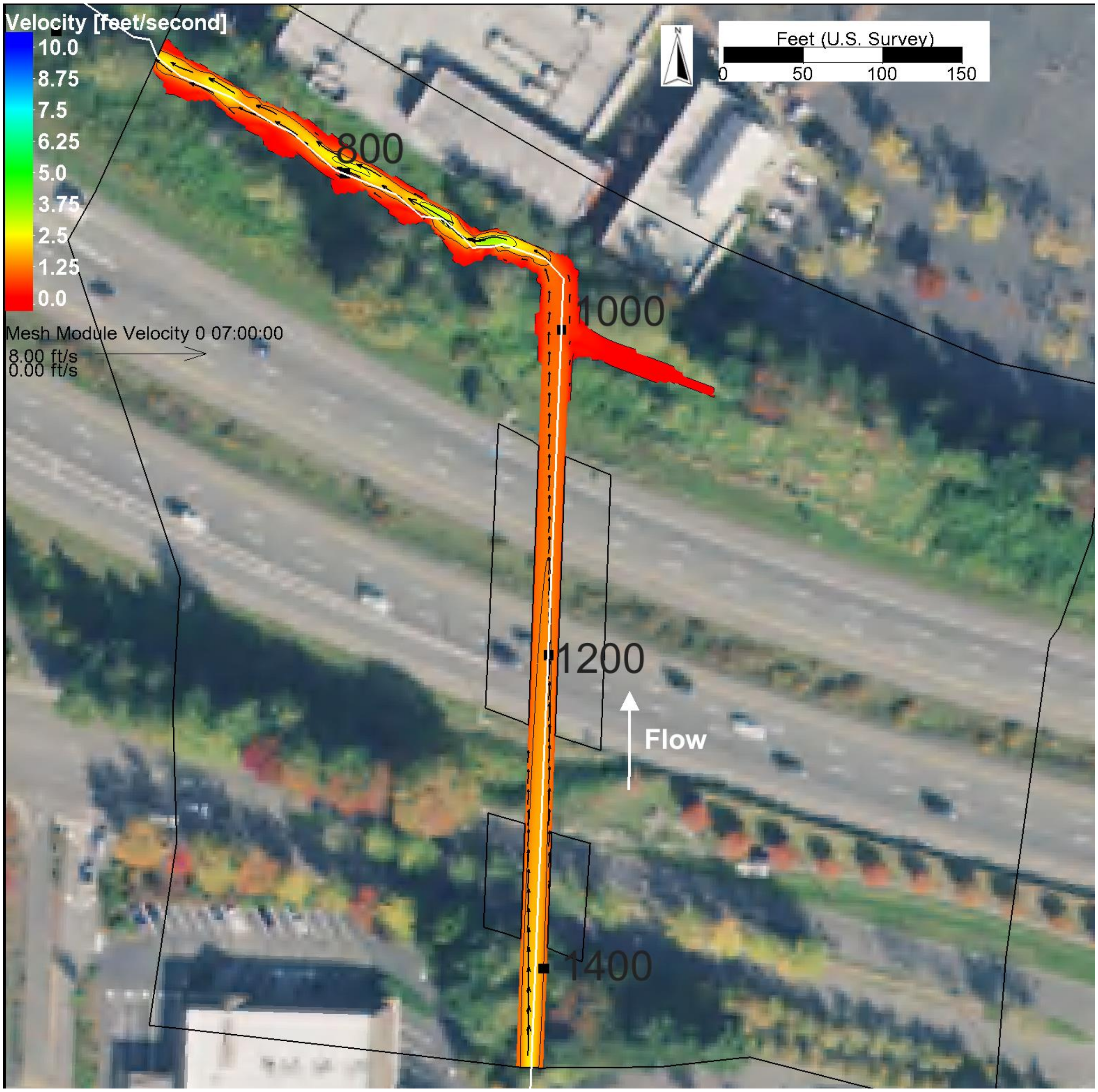


Figure C-22: Proposed Conditions 2-Year Velocity Near the Proposed Crossing

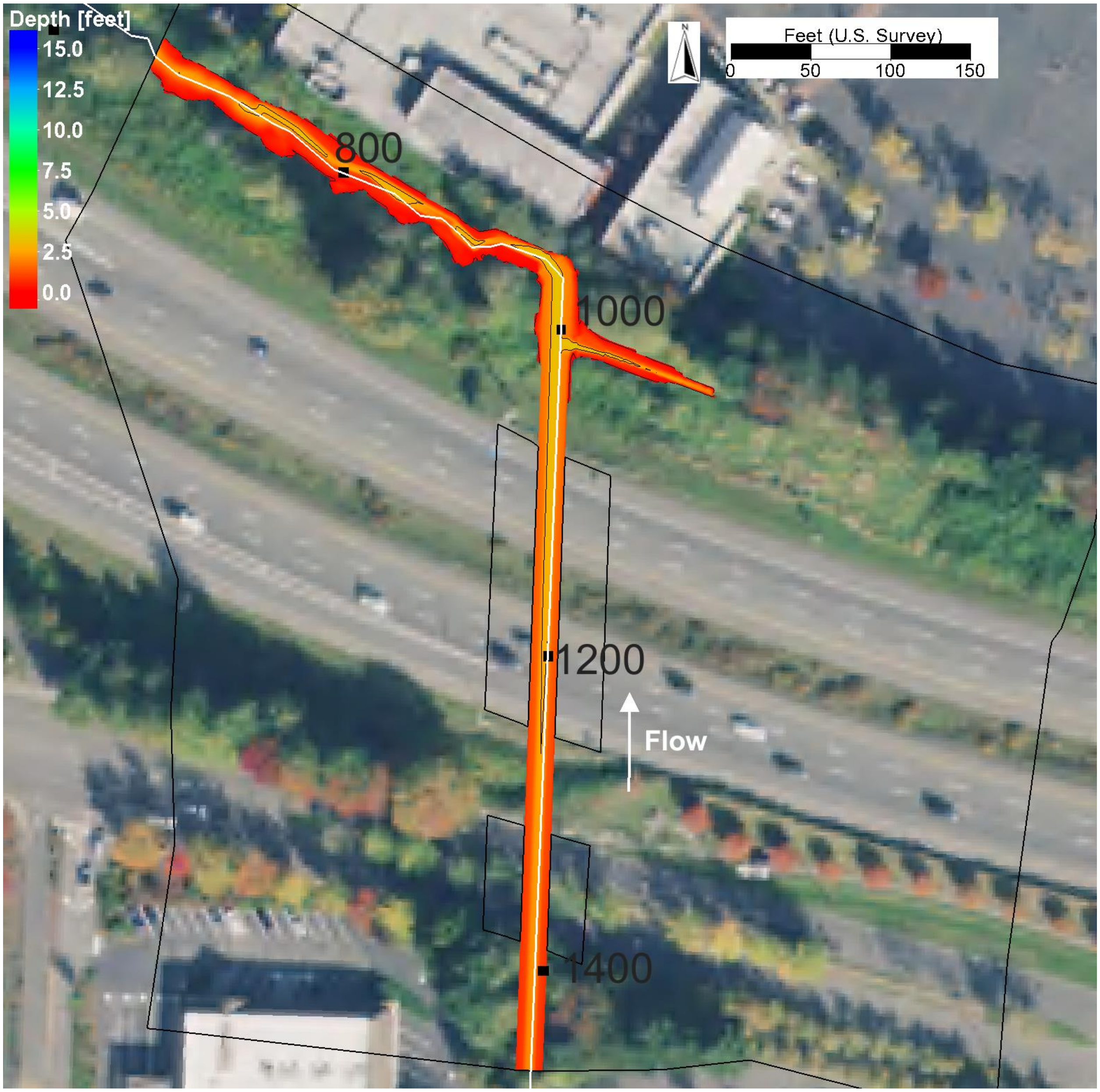


Figure C-23: Proposed Conditions 2-Year Depth Near the Proposed Crossing

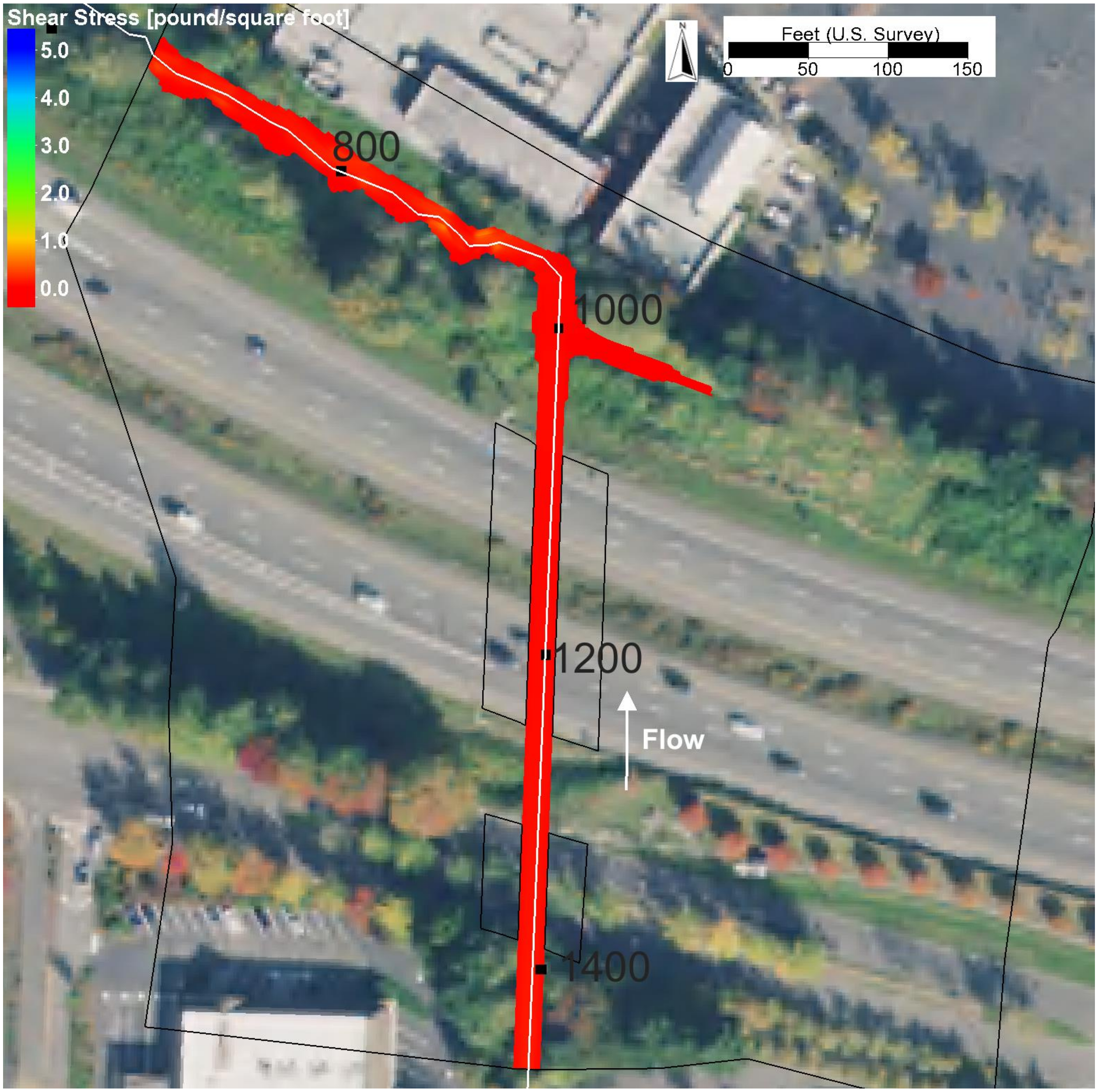


Figure C-24: Proposed Conditions 2-Year Shear Stress Near the Proposed Crossing

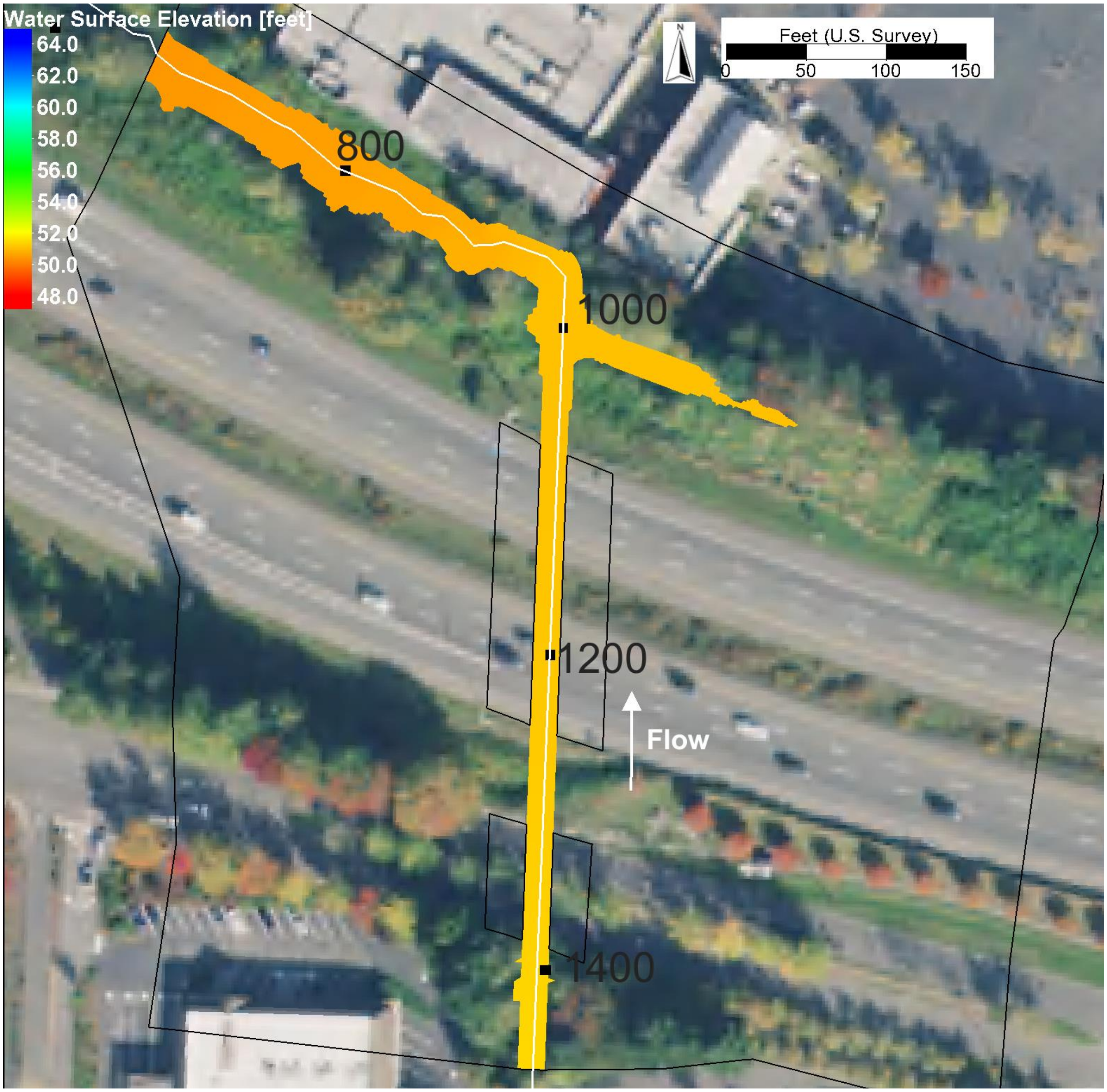


Figure C-25: Proposed Conditions 100-Year Water Surface Elevation Near the Proposed Crossing

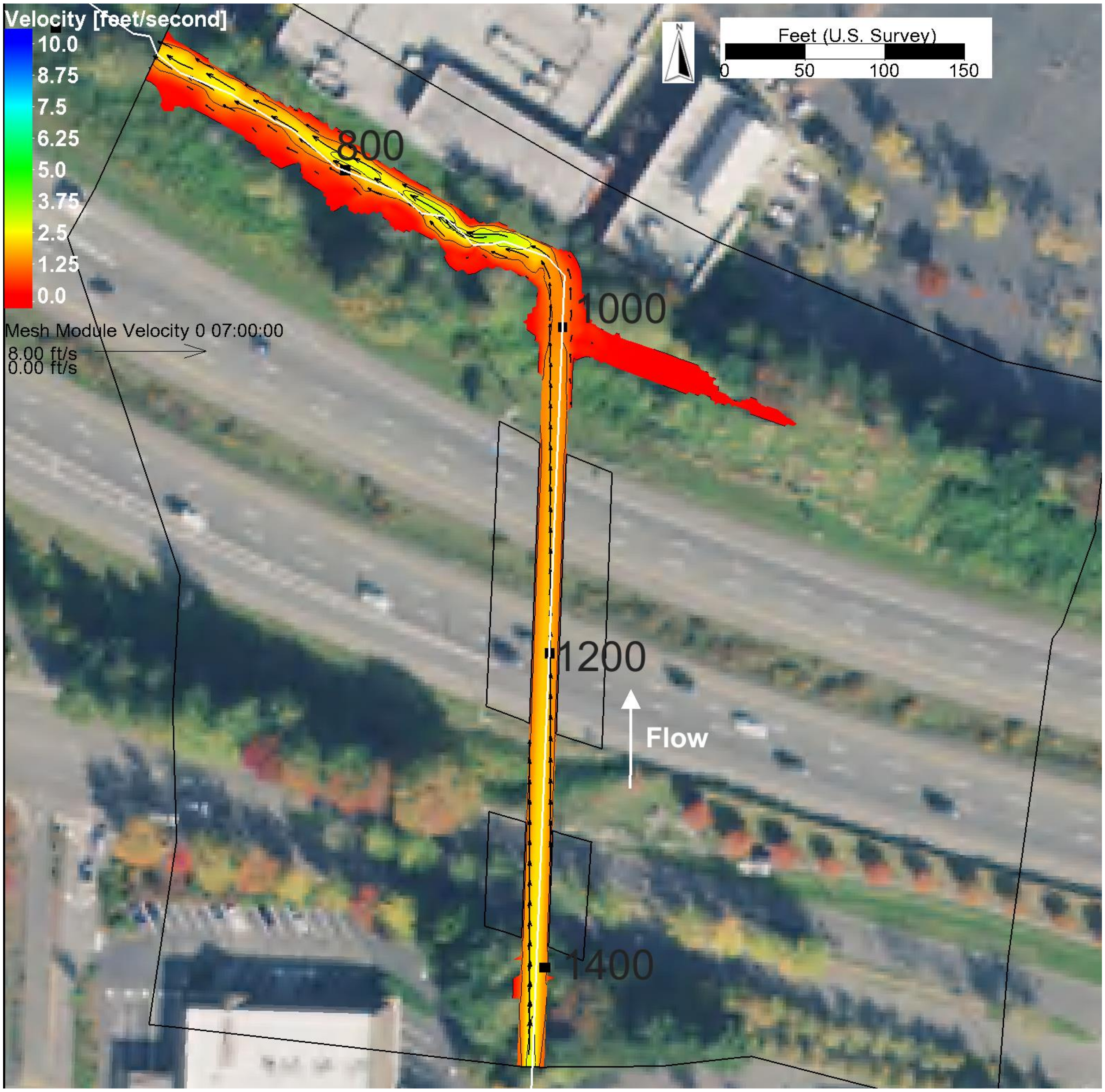


Figure C-26: Proposed Conditions 100-Year Velocity Near the Proposed Crossing

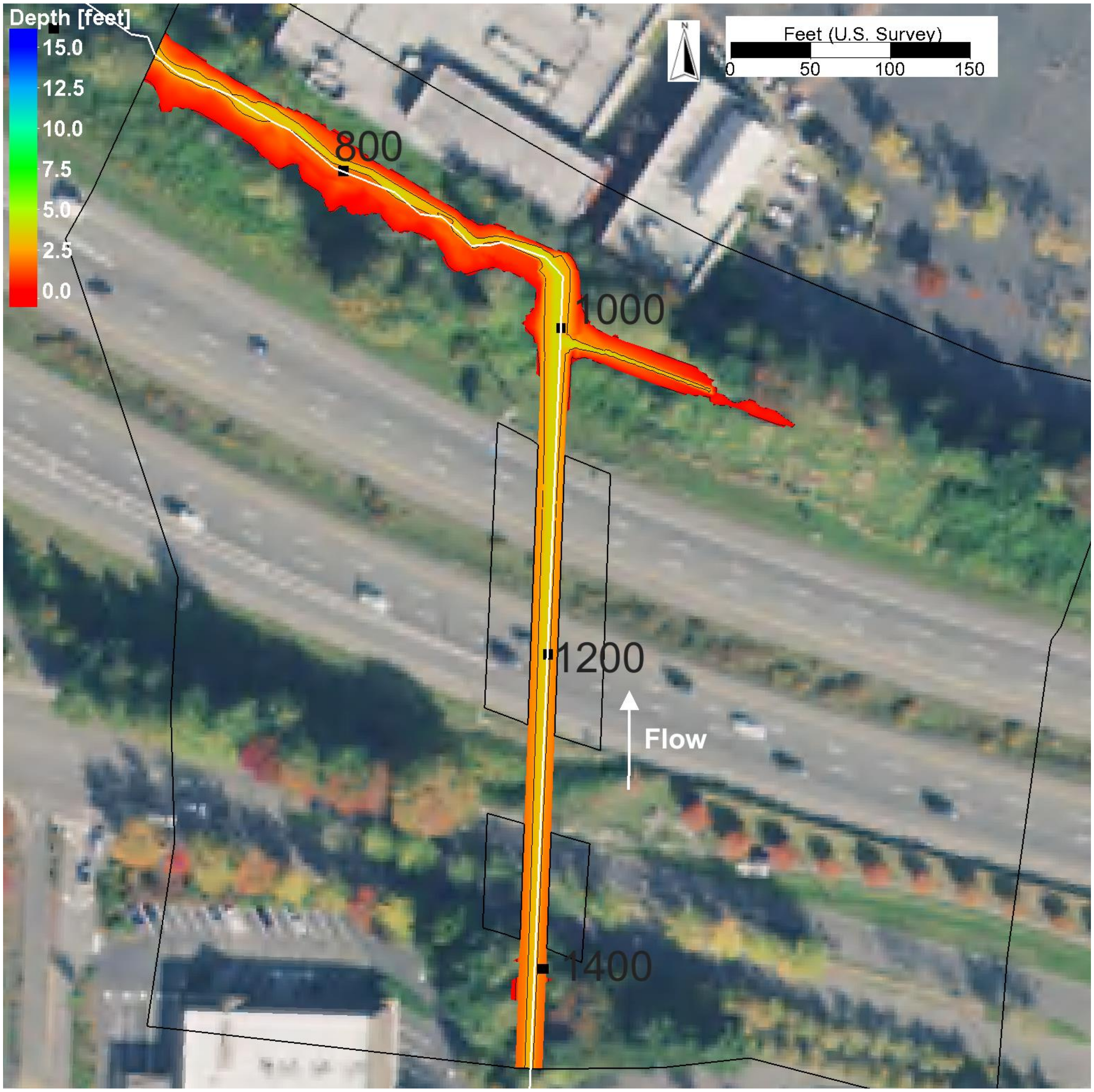


Figure C-27: Proposed Conditions 100-Year Depth Near the Proposed Crossing

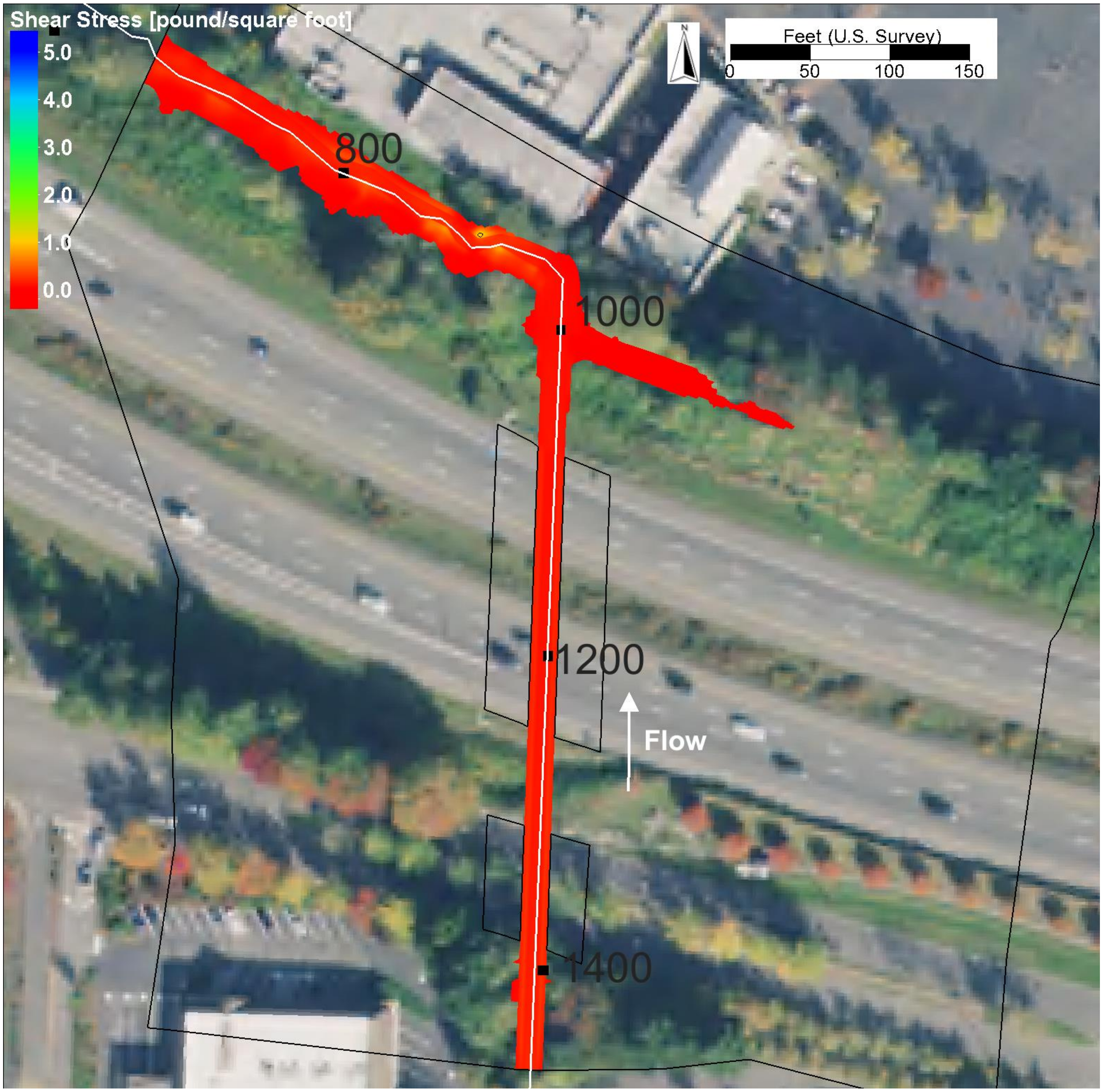


Figure C-28: Proposed Conditions 100-Year Shear Stress Near the Proposed Crossing

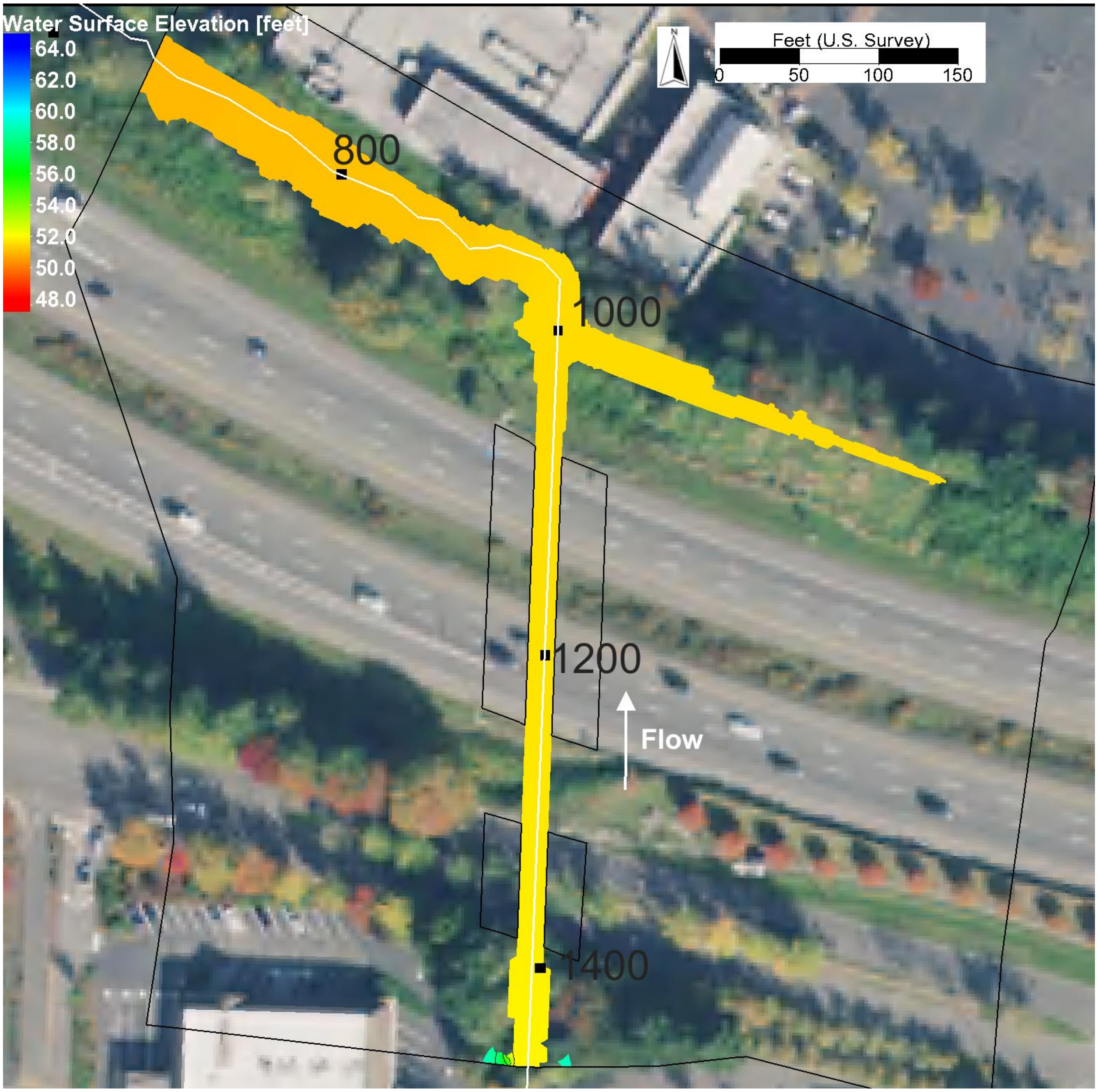


Figure C-29: Proposed Conditions 2080 Projected 100-Year Water Surface Elevation Near the Proposed Crossing

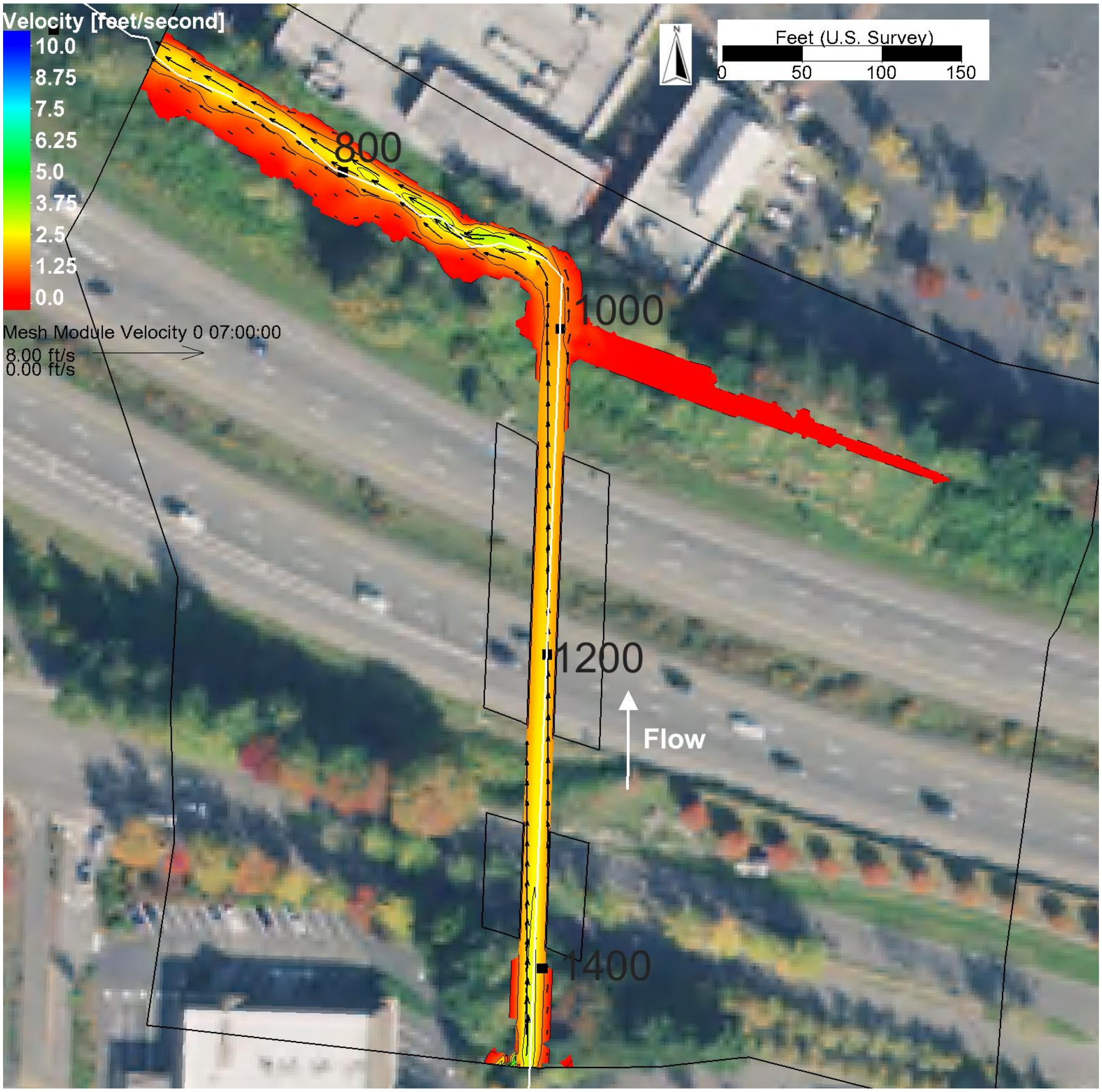


Figure C-30: Proposed Conditions 2080 Projected 100-Year Velocity Near the Proposed Crossing

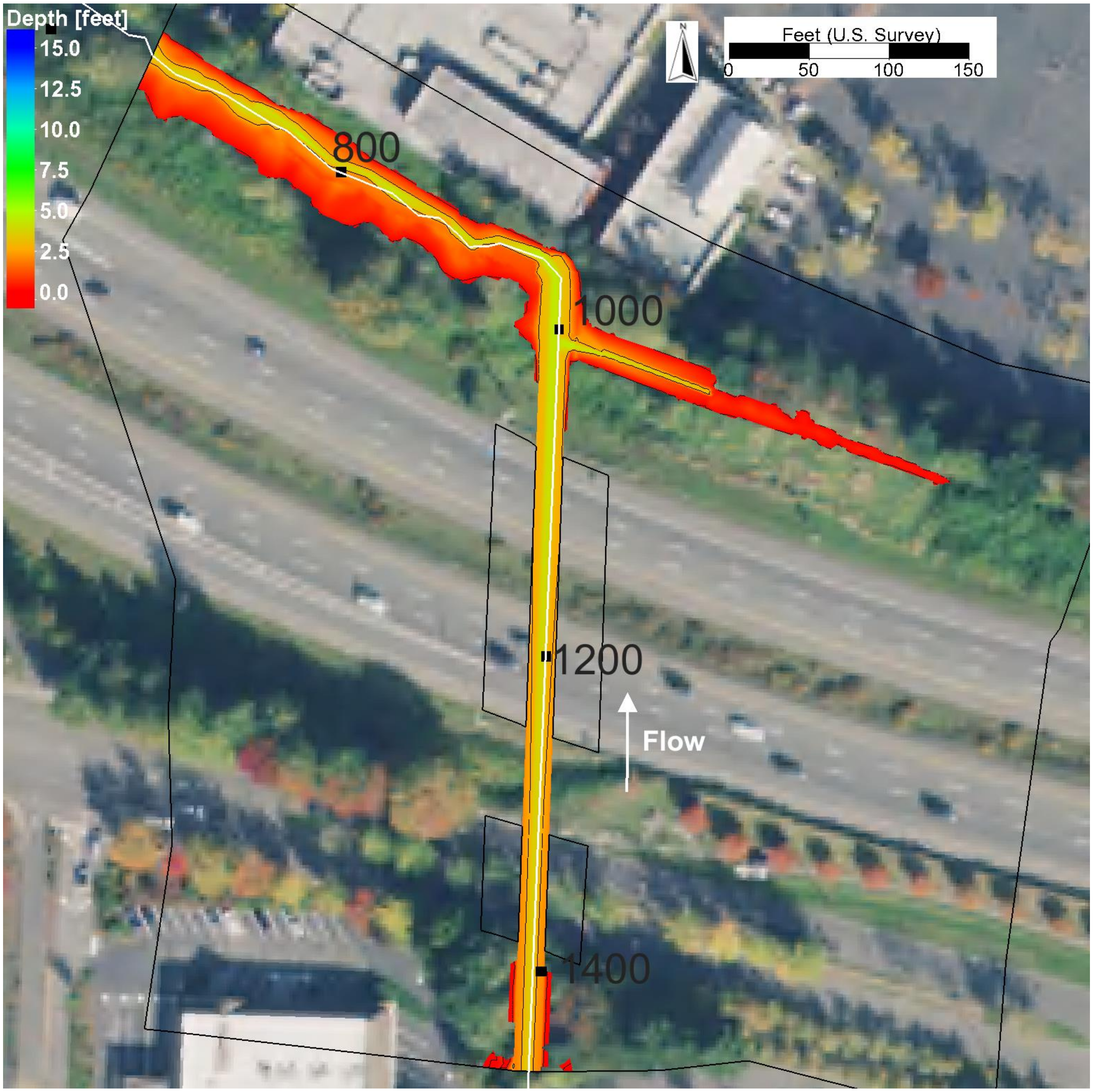


Figure C-31: Proposed Conditions 2080 Projected 100-Year Depth Near the Proposed Crossing

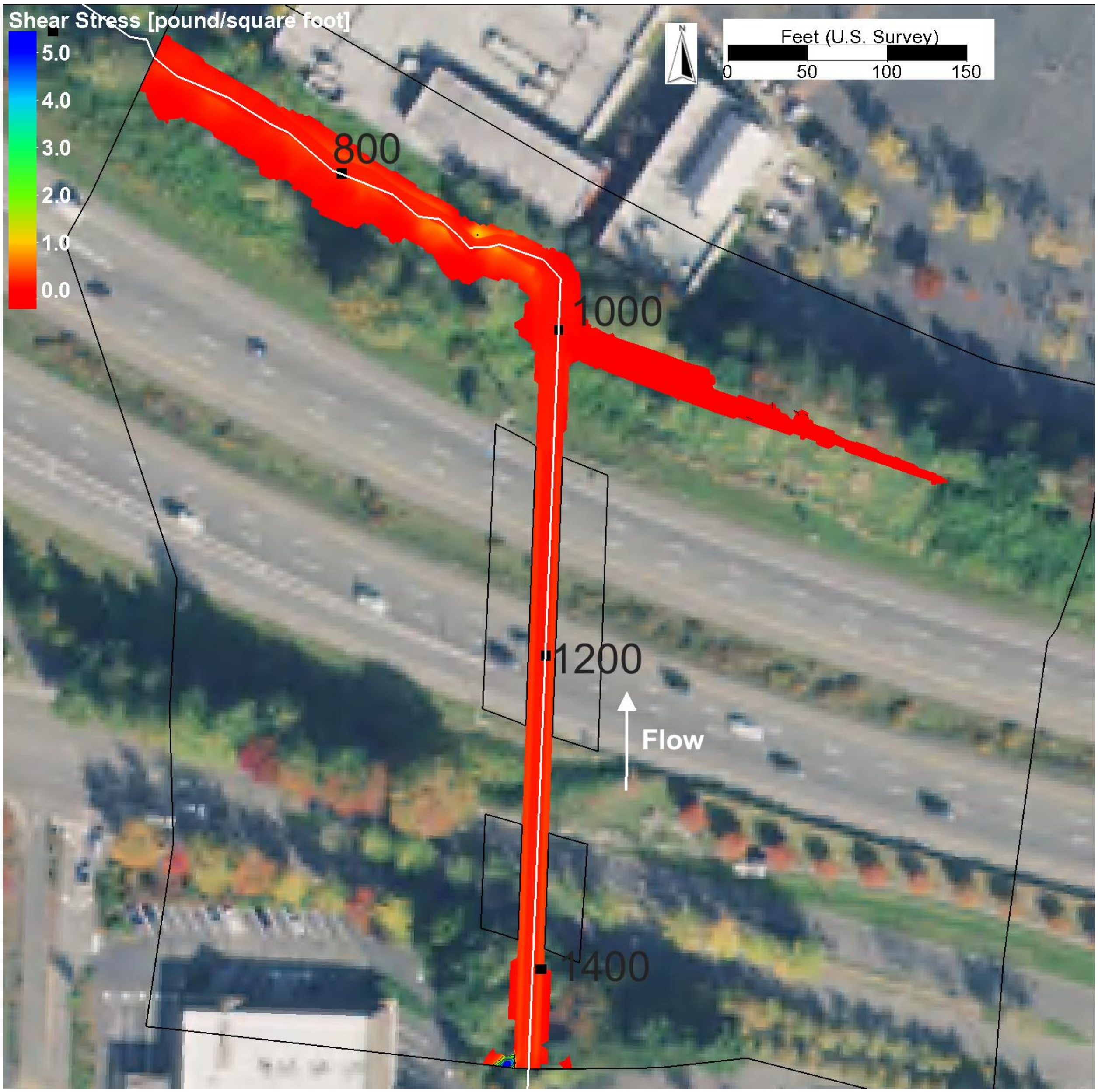


Figure C-32: Proposed Conditions 2080 Projected 100-Year Shear Stress Near the Proposed Crossing

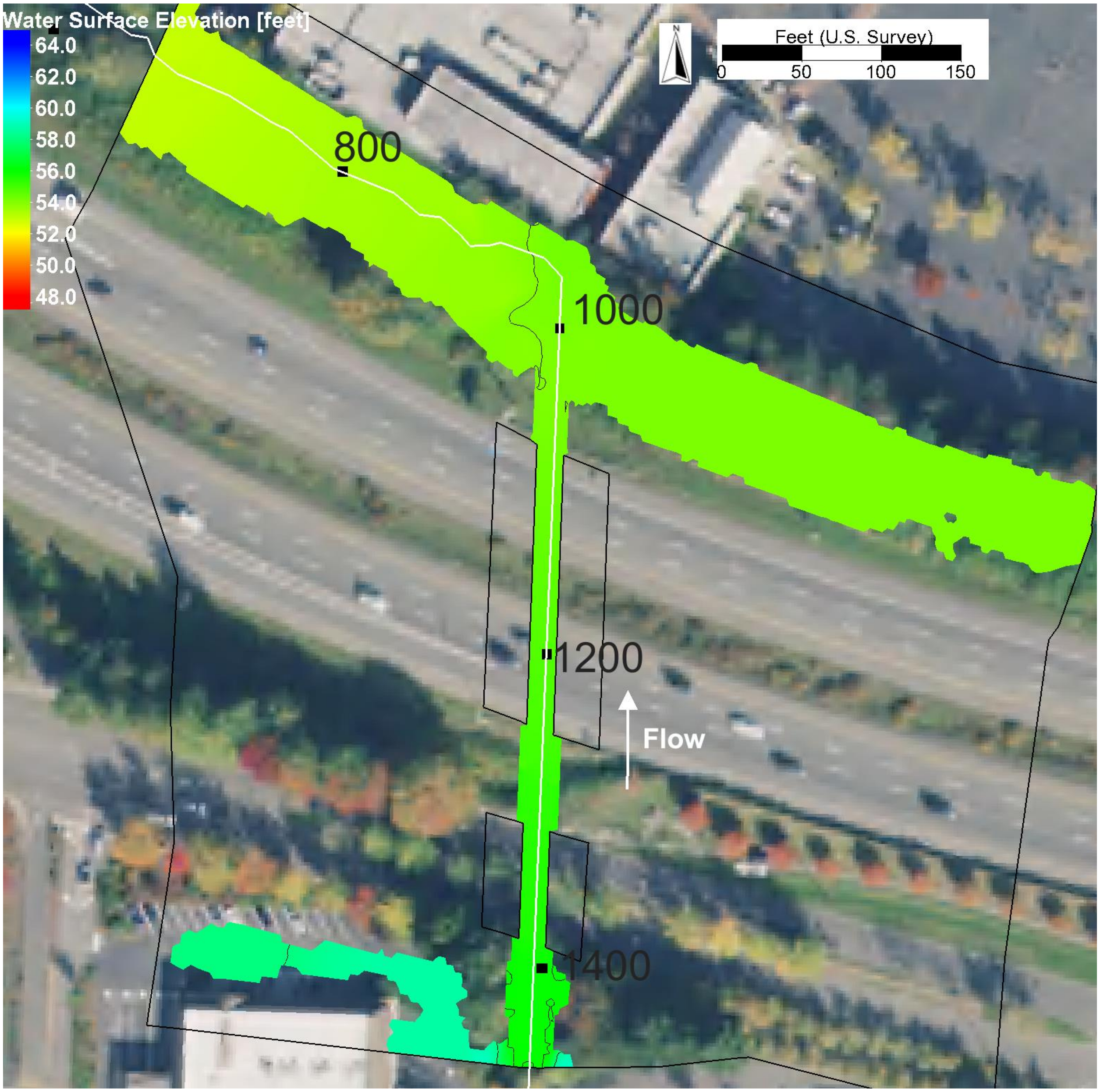


Figure C-33: Proposed Conditions 100-Year Overflow Water Surface Elevation Near the Proposed Crossing

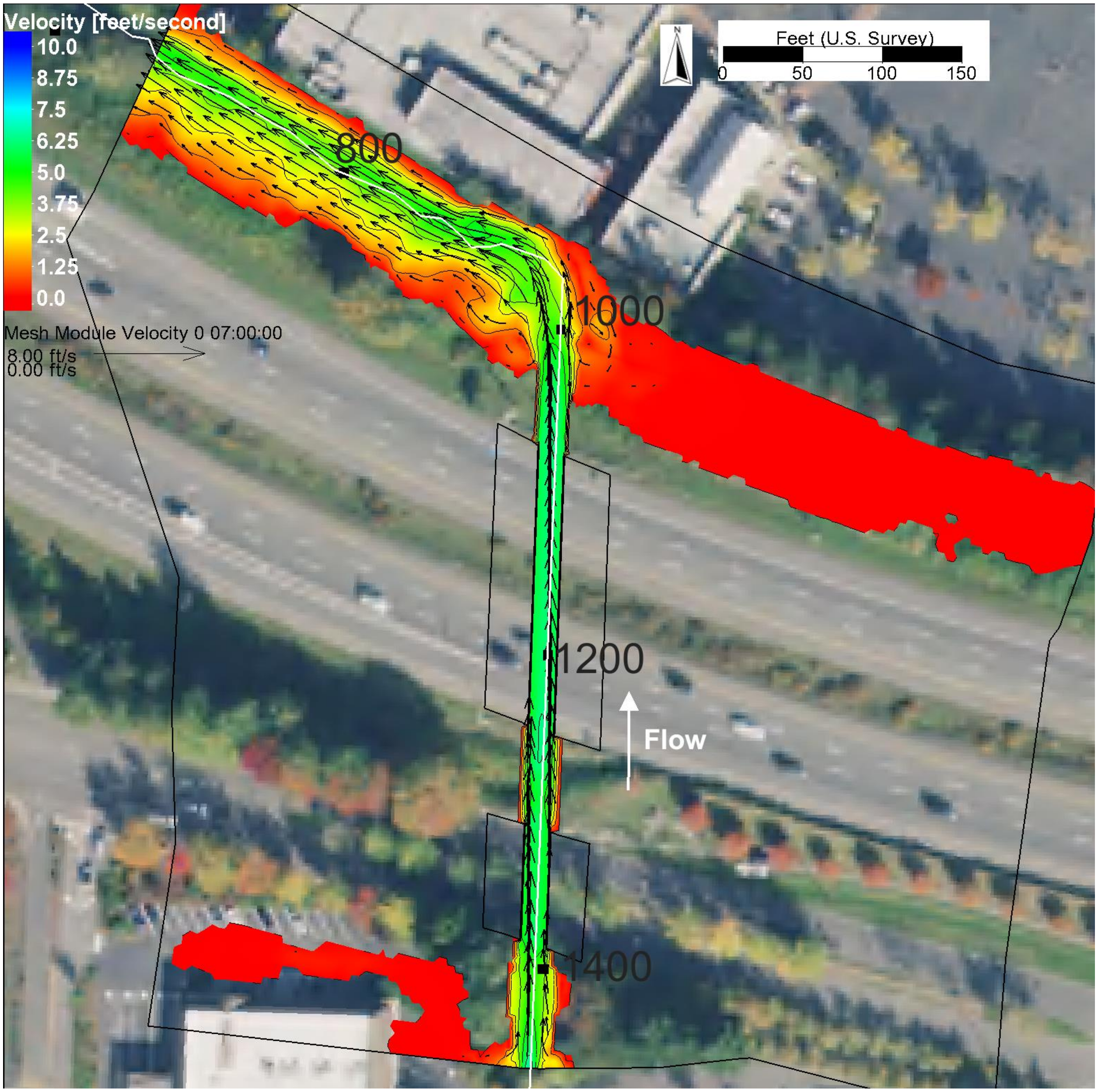


Figure C-34: Proposed Conditions 100-Year Overflow Velocity Near the Proposed Crossing

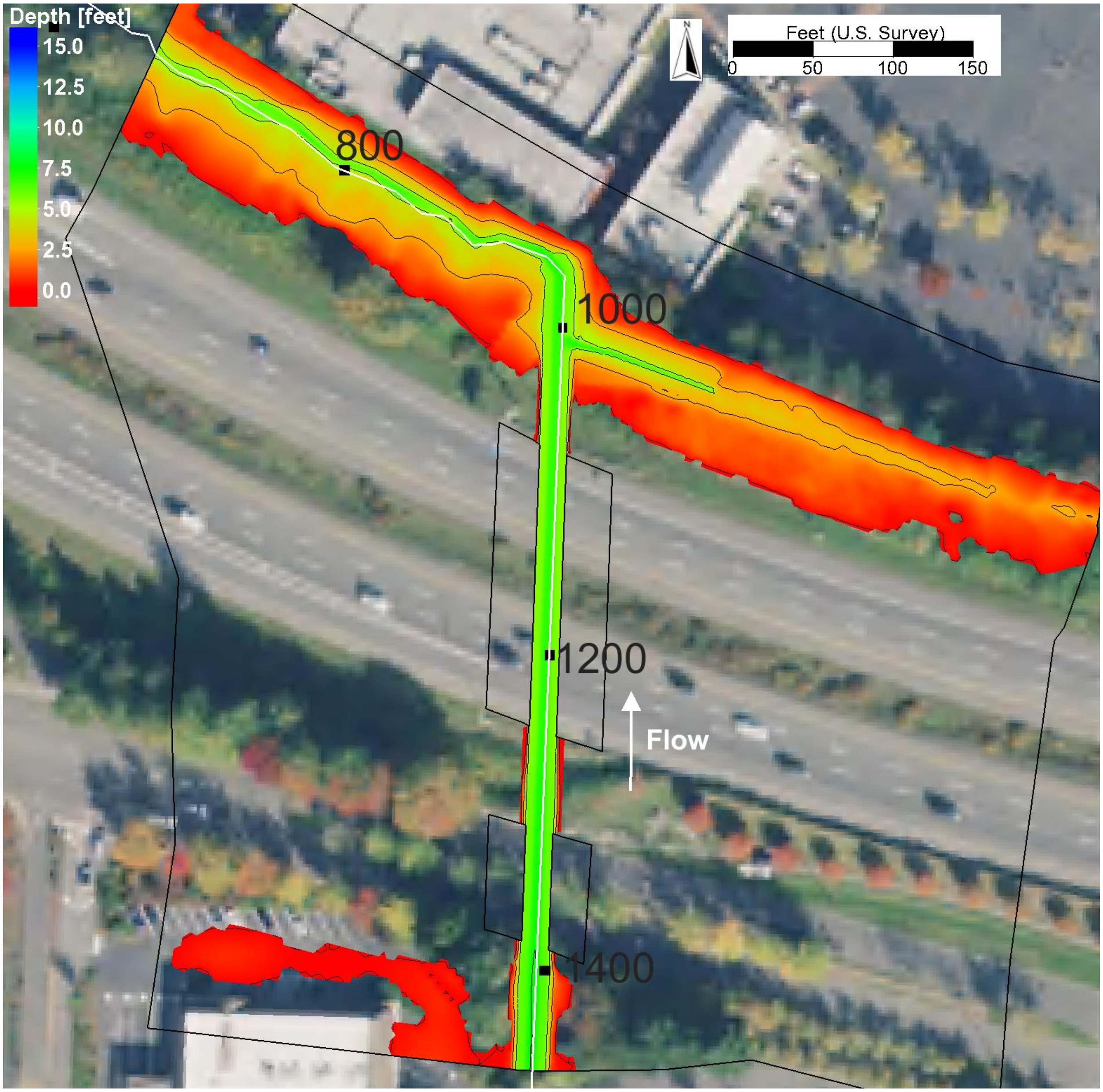


Figure C-35: Proposed Conditions 100-Year Overflow Depth Near the Proposed Crossing

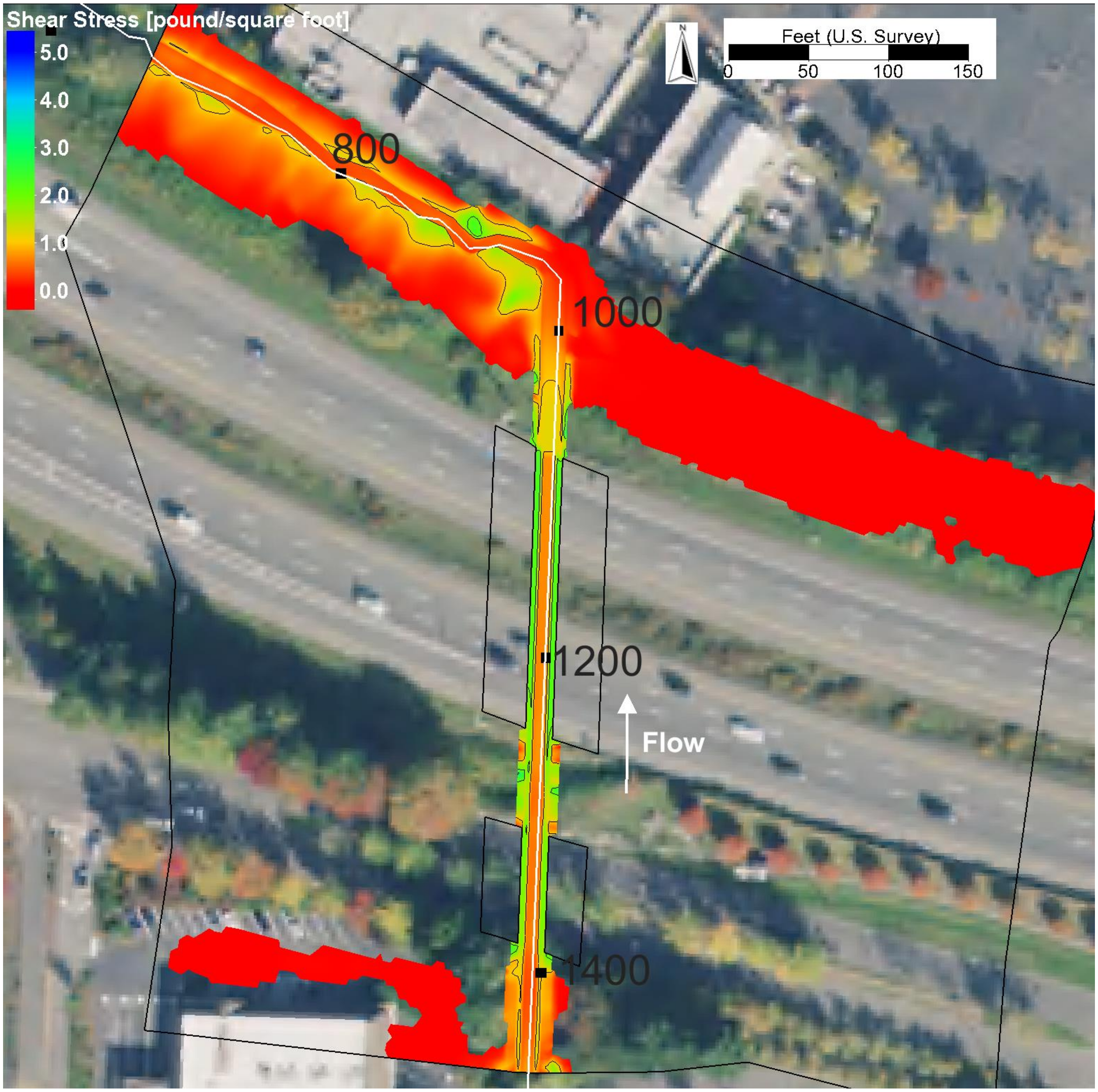


Figure C-36: Proposed Conditions 100-Year Overflow Shear Stress Near the Proposed Crossing

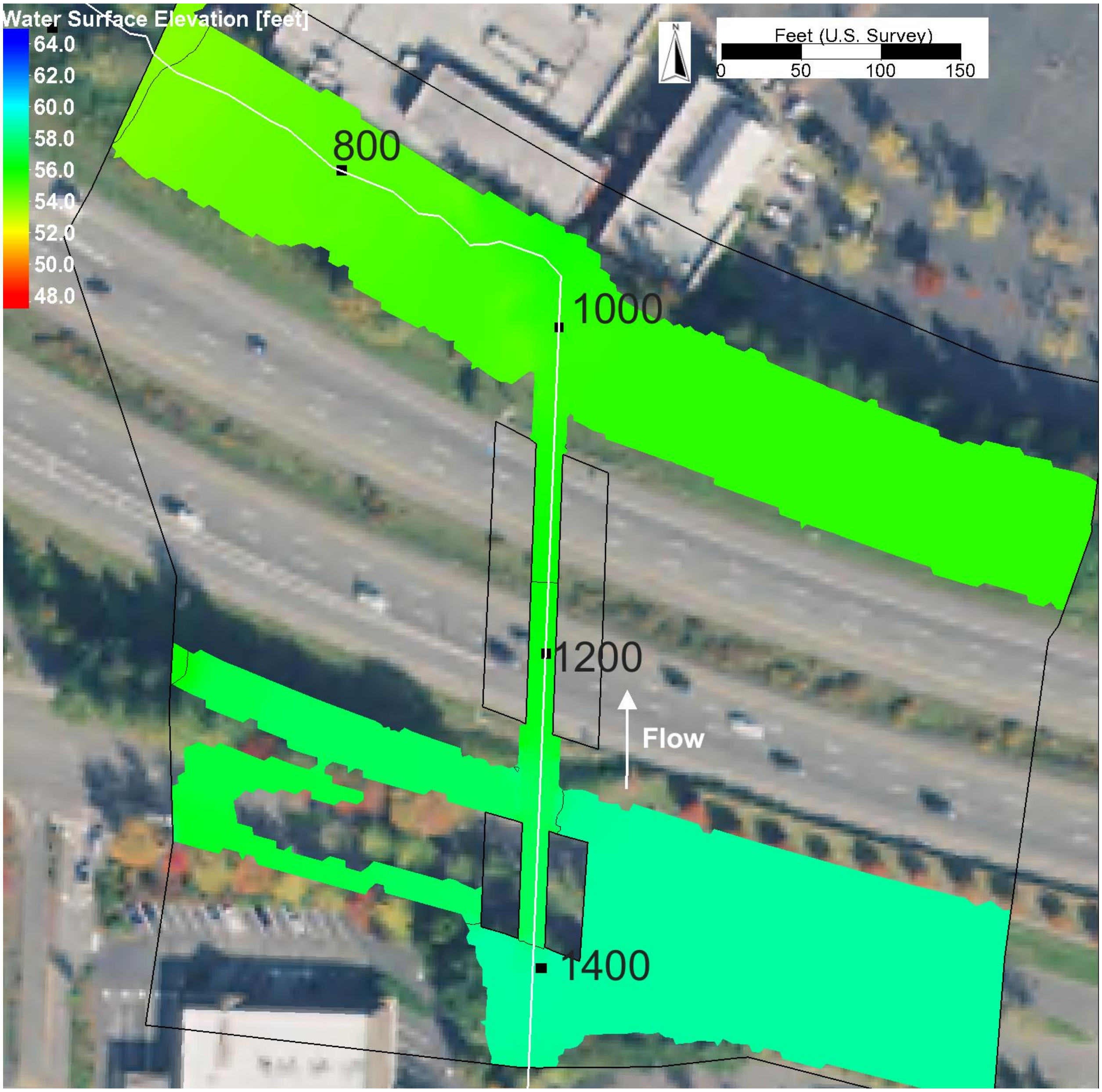


Figure C-37: Proposed Conditions 500-Year Overflow Water Surface Elevation Near the Proposed Crossing

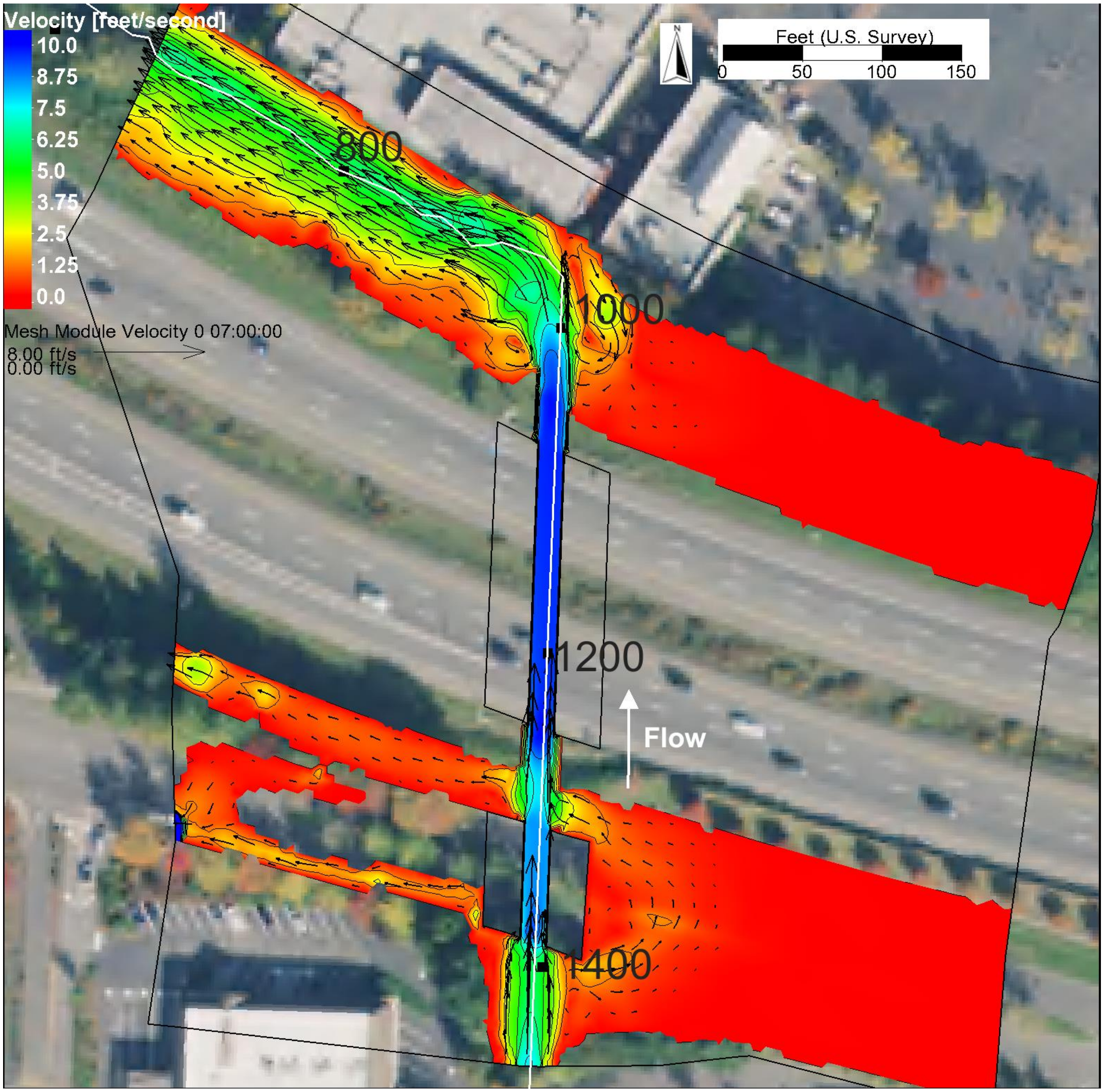


Figure C-38: Proposed Conditions 500-Year Overflow Velocity Near the Proposed Crossing

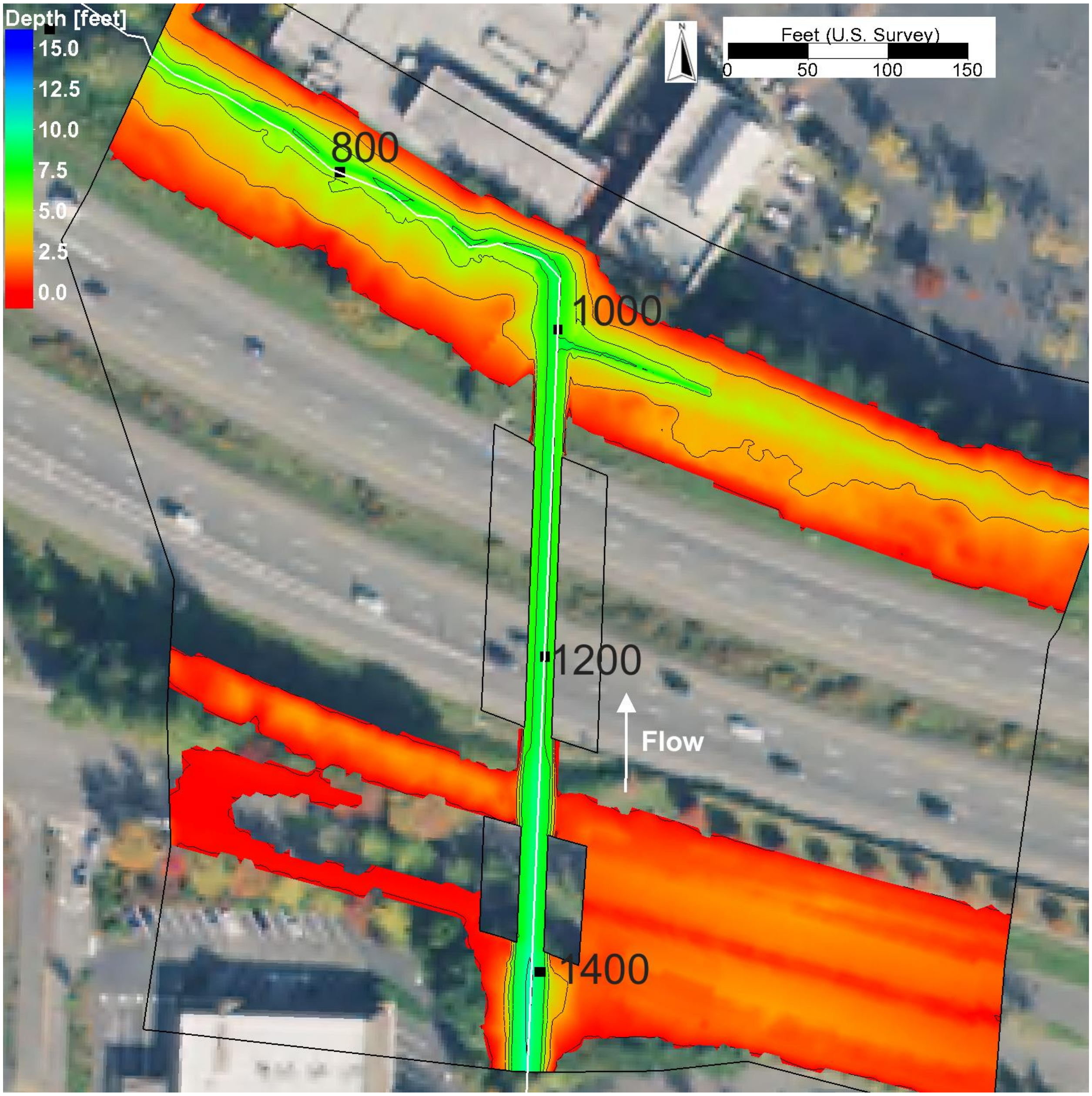


Figure C-39: Proposed Conditions 500-Year Overflow Depth Near the Proposed Crossing

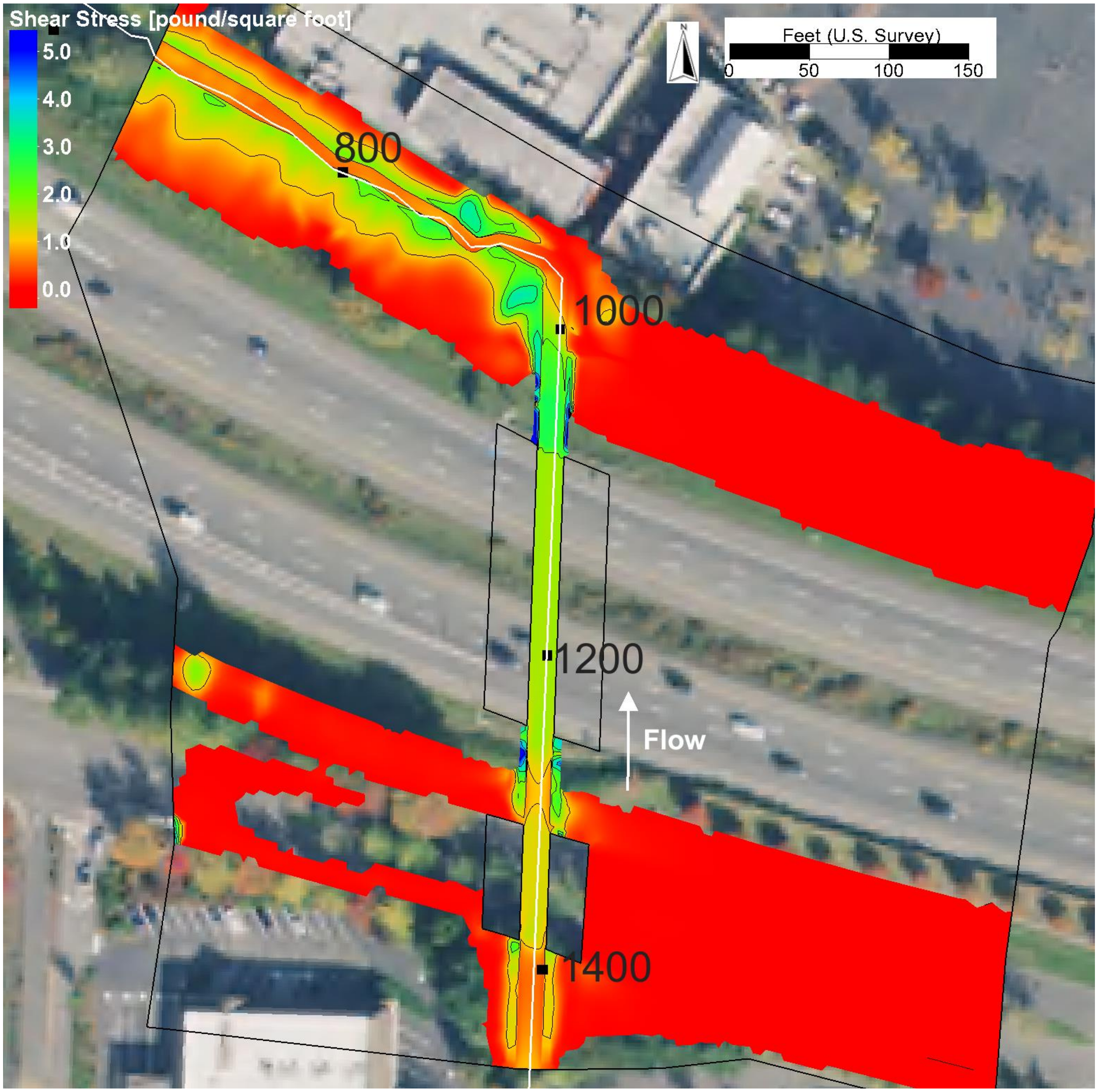


Figure C-40: Proposed Conditions 500-Year Overflow Shear Stress Near the Proposed Crossing

Appendix D - Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material

References:

Bathurst, J.C. (1987) Critical Conditions for Movement i

Hydraulical Sciences Pub. Vol. 165.

Gradation relationships from WDFW Design of Road Cu

Project:	I90 MP 16.21 Unnamed Tributary to Tibbetts Creek
By:	T. Rockhill

Design Gradation:				
Location: Proposed Crossing				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
Feet	**0.5**	**0.2**	**0.1**	**0.03**
Inches	**6.0**	**1.9**	**0.8**	**0.4**
Millimeters	**152**	**48**	**20**	**10**

Design Gradation:				
Location: Pebble Count 3 (Sta. 07+07)				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
Feet	**0.4**	**0.1**	**0.1**	**0.04**
Inches	**5.0**	**1.4**	**1.1**	**0.5**
Millimeters	**127**	**36**	**28**	**13**

Design Gradation:				
Location: Pebble Count 2 (Sta 09+15)				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
Feet	**0.2**	**0.1**	**0.0**	**0.02**
Inches	**1.8**	**0.9**	**0.5**	**0.2**
Millimeters	**46**	**23**	**13**	**5**

Design Gradation:				
Location: Pebble Count 4 (Sta 04+45)				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
Feet	**0.4**	**0.1**	**0.1**	**0.03**
Inches	**5.0**	**1.6**	**0.9**	**0.3**
Millimeters	**127**	**41**	**23**	**8**

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		**Streambed**	**Streambed Cobbles**					**Streambed Boulders**			**D_{size}**
[in]	**[mm]**	**Sediment**	**4"**	**6"**	**8"**	**10"**	**12"**	**12"-18"**	**18"-28"**	**28"-36"**	
36.0	**914**									**100**	**110.0**
32.0	**813**									50	**110.0**
28.0	**711**								**100**		**110.0**
23.0	**584**								50		**110.0**
18.0	**457**							**100**			**110.0**
15.0	**381**							50			**105.0**
12.0	**305**						**100**				**100.0**
10.0	**254**					**100**	**80**				**100.0**
8.0	**203**				**100**	**80**	68				**100.0**
6.0	**152**			**100**	**80**	68	57				**100.0**
5.0	**127**			**80**	68	57	**45**				**95.0**
4.0	**102**		**100**	71	57	**45**	39				**92.8**
3.0	**76.2**		**80**	63	**45**	38	33				**90.6**
2.5	**63.5**	**100**	65	54	37	32	26				**88.4**
2.0	**50.8**	**80.0**	50	**45**	29	25	20				**71.3**
1.5	**38.1**	74	**35**	32	21	18	14				**63.2**
1.0	**25.4**	**68**	20	18	13	12	8				**55.2**
0.50	**12.7**	51	**5**	**5**	**5**	**5**	**5**				**39.7**
0.19	**4.75**	**35**									**26.3**
0.02	**0.425**	**10**									**7.5**
0.003	**0.0750**	**7**									**5.3**
% per category		**75**	**0**	**25**	**0**	**0**	**0**	**10**	**0**	**0**	*--> 110%*
% Cobble & Sediment		**75.0**	**0.0**	**25.0**	**0.0**	**0.0**	**0.0**	**10.0**	**0.0**	**0.0**	*100.0%*

Project:	**I90 MP 16.21**
Location:	**Issaquah, WA**
Stream:	**Unnamed Tributary to Tibbetts Creek**
Engineer:	**T. Rockhill**
Geomorphologist:	**A. Diffucy**
Date Collected:	**5/14/2020**
Date Analyzed:	**7/15/2020**
Checked by and when:	

Design Gradation:				
Location:	Proposed Crossing			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
Feet	0.5	0.2	0.1	0.03
Inches	6.0	1.9	0.8	0.4
Millimeters	152	48	20	10

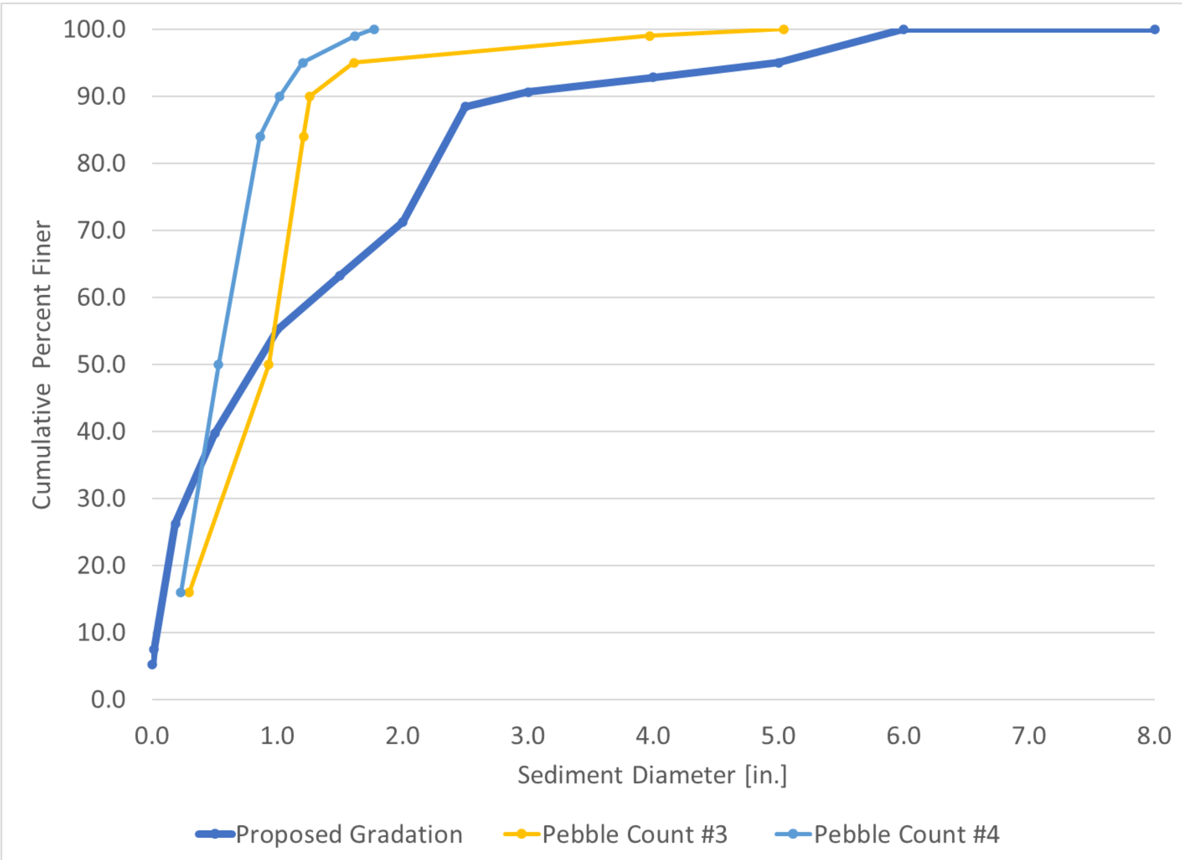
Limitations:	**Check:**
D_{84} must be between 0.40 in and 10 in	YES
uniform bed material (Di < 20-30 times D50)	YES
Slopes less than 5%	YES
Sand/gravel streams with high relative submergence	YES

Cross Section:	**Through Structure**

Event	Q [cfs]	Energy Slope [ft/ft] (S)	Bankfull Width [ft] (Wbf)	Active Bed Width (Wa) [ft]	Bankfull Hydraulic Radius [ft]
500-year Overflow	1250.0	0.030	17.0	17.0	2.0
100-year Overflow	610.0	0.030	17.0	17.0	2.0
50-year Overflow	370.0	0.030	17.0	17.0	2.0
500-year	85.0	0.031	17.0	17.0	2.0
100-year	73.0	0.031	17.0	17.0	2.0
50-year	68.0	0.032	17.0	17.0	2.0
25-year	62.0	0.032	17.0	17.0	2.0
10-year	54.0	0.032	17.0	17.0	2.0
2-year	38.0	0.032	17.0	17.0	2.0

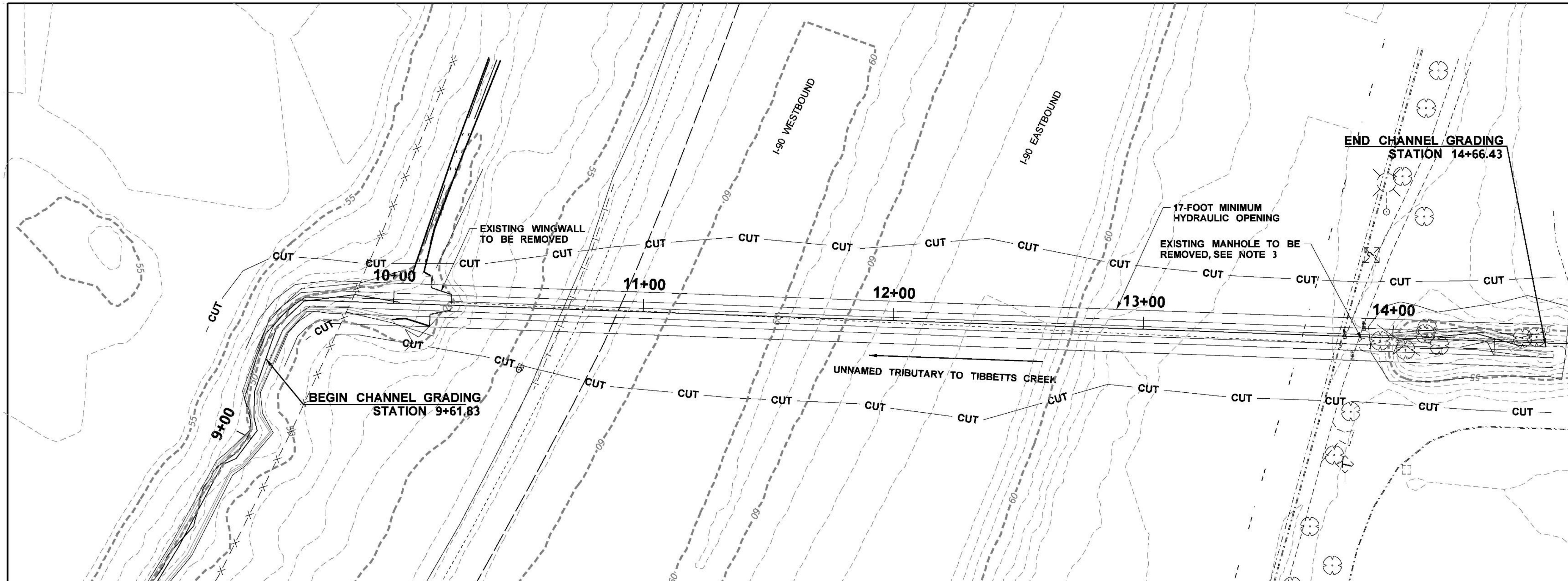
γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.04	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed
D50	0.8	

Rock Size		τ_{ci}	Simulated Proposed Shear Stress [lb/ft2]								
			2-year	10-year	25-year	50-year	100-year	500-year	50-year Overflo	100-year Overflo	500-year Overflo
[in]	[mm]		0.07	0.08	0.08	0.09	0.10	0.12	0.60	1.02	1.22
36.0	914	0.84	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion
32.0	813	0.81	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion
28.0	711	0.78	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion
23.0	584	0.73	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion
18.0	457	0.68	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion
15.0	381	0.64	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion
12.0	305	0.60	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion
10.0	254	0.57	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
8.0	203	0.53	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
6.0	152	0.49	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
5.0	127	0.46	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
4.0	102	0.43	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
3.0	76.2	0.40	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
2.5	63.5	0.38	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
2.0	50.8	0.35	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
1.5	38.1	0.32	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
1.0	25.4	0.29	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
0.50	12.7	0.23	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
0.19	4.75	0.17	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
0.02	0.425	0.08	No Motion	No Motion	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.003	0.0750	0.05	Motion	Motion	Motion	Motion	Motion	Motion	Motion	Motion	Motion



100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Cumulative Percent Finer
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Sediment Diameter [in.]
Proposed Gradation
Pebble Count #3
Pebble Count #4

Appendix E - Stream Plan Sheets, Profile, Details



NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.

2. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE, TYPE, SIZE, AND LOCATION.

3. EXISTING 4-FOOT DIAMETER CULVERT AND MANHOLE TO BE REMOVED. FINAL STRUCTURE DESIGN TO BE DETERMINED.

LEGEND

10+50	STREAM ALIGNMENT
310	EXISTING INDEX CONTOUR
	EXISTING INTERMEDIATE CONTOUR
	EXISTING FENCE
	EXISTING GUARDRAIL
	EXISTING EDGE OF PAVEMENT
	EXISTING EDGE OF GRAVEL DRIVE
	EXISTING PIPE CENTERLINE
	EXISTING POWER POLE
	EXISTING POWER POLE
	EXISTING STREAM THALWEG
	EXISTING CREEK BANK
1+00	NEW STREAM ALIGNMENT
CUT	LIMITS OF EXCAVATION
	NEW STRUCTURE
	EXISTING SIGN
	EXISTING CATCH BASIN
	EXISTING TREE
	EXISTING POWER POLE

0 20 40
SCALE IN FEET

PRELIMINARY NOT FOR CONSTRUCTION

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DATE	8/6/2020
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DESIGNED BY	T. ROCKHILL
ENTERED BY	
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER
CONTRACT NO. | LOCATION NO.

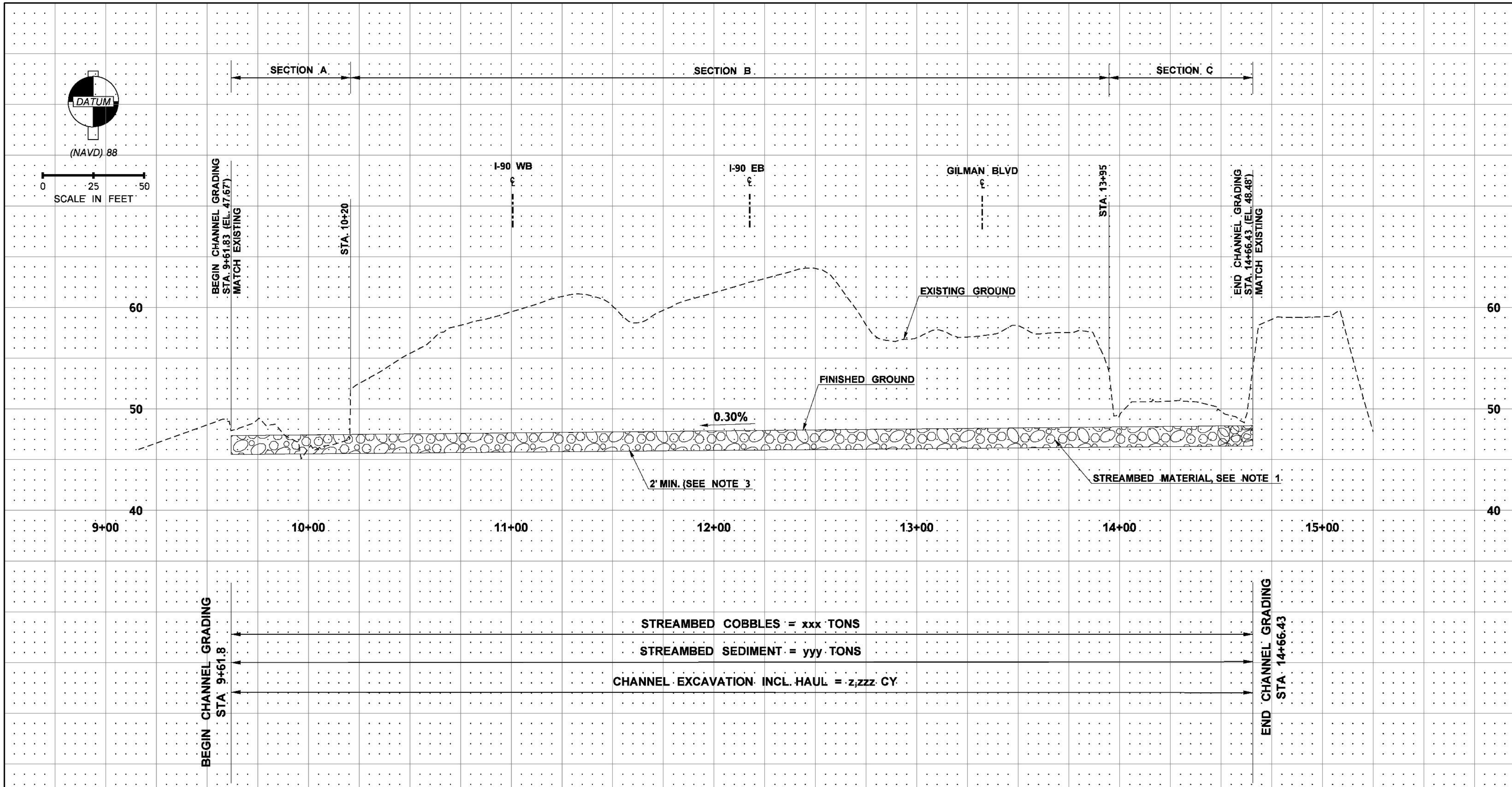
P.E. STAMP BOX DATE
P.E. STAMP BOX DATE

Washington State Department of Transportation

I-90 MP16.21
UNNAMED TRIBUTARY TO TIBBETS CREEK

PROPOSED STREAM PLAN

PLAN REF NO
SHEET 1 OF 3 SHEETS



NOTES:

1. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND COARSE BANDS. FINAL INSTALLATION WILL PROVIDE A WELL GRADED MIX OF STREAMBED SEDIMENTS AND STREAMBED COBBLES.
2. FOR STRUCTURE DETAILS SEE SHEET XX.
3. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR.
4. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WING WALLS TO BE DETERMINED.

PRELIMINARY NOT FOR CONSTRUCTION

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CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

DATE
P.E. STAMP BOX

DATE
P.E. STAMP BOX

Washington State Department of Transportation

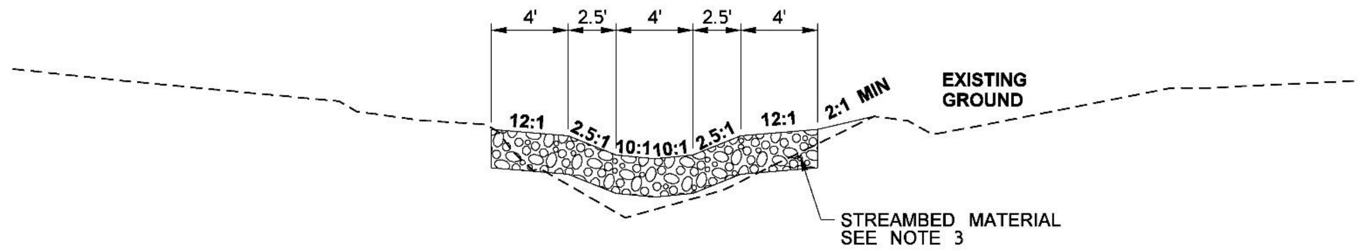
I-90 MP16.21
UNNAMED TRIBUTARY TO TIBBETS CREEK

STREAM PROFILE

PLAN REF. NO.

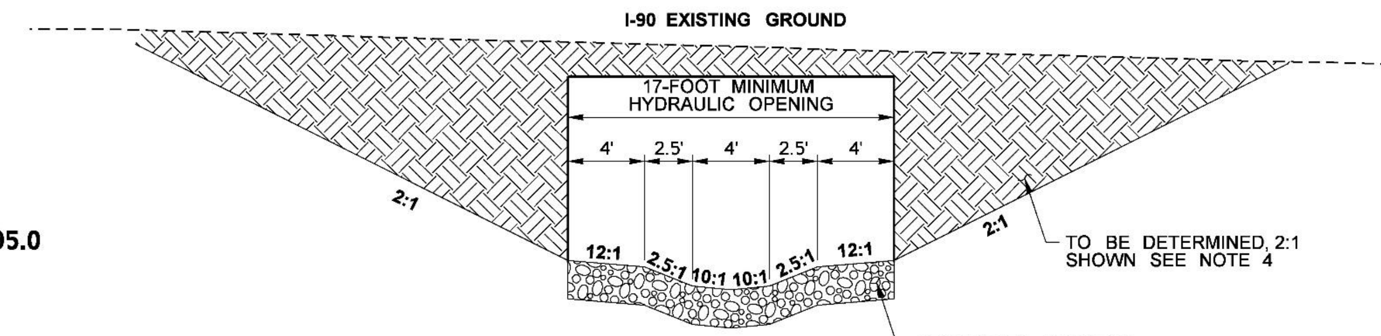
SHEET 2 OF 3 SHEETS

SECTION A
STATION 9+61.83 TO 10+20.0



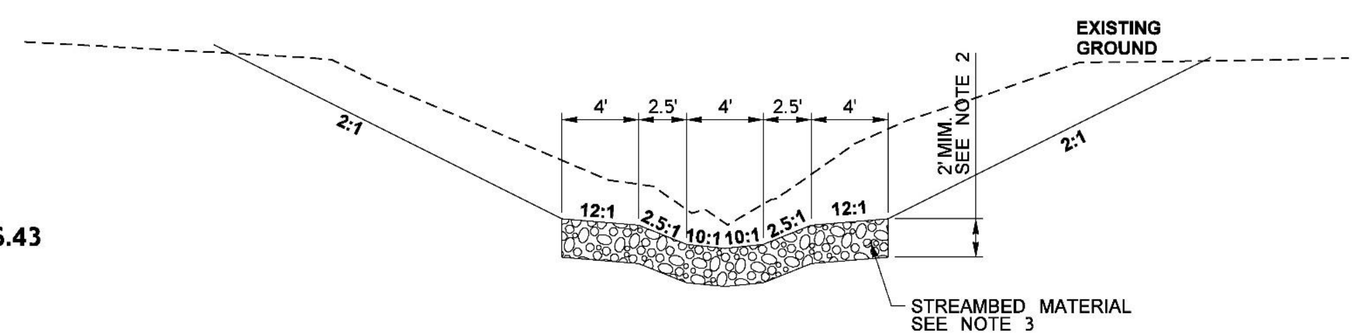
DOWNSTREAM

SECTION B
STATION 10+20.0 TO 13+95.0



TYPICAL CHANNEL

SECTION C
STATION 13+95.0 TO 14+66.43



UPSTREAM

NOTES:

1. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL GRADING LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE AND LOCATION.
2. MATERIAL DEPTH IS APPROXIMATE, FINAL DEPTH TO BE DETERMINED AFTER SCOUR ANALYSIS.
3. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND STREAMBED MATERIAL LIFTS.
4. ESTIMATED AREA OF POTENTIAL IMPACTS ARE SHOWN FOR ILLUSTRATION PURPOSED ONLY, FINAL GRADING LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE, AND LOCATION.

PRELIMINARY NOT FOR CONSTRUCTION

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DESIGNED BY	T. ROCKHILL
ENTERED BY	
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

I-90 MP16.21
UNNAMED TRIBUTARY TO TIBBETS CREEK

STREAM DETAILS

PLAN REF NO

SHEET 3 OF 3 SHEETS

Appendix F - Scour Calculations

Appendix F has been left blank as no scour calculations have been conducted and reviewed yet for this PHD.

Appendix G - Manning's Calculations

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name:	I90 MP01621 Trib to Tibbetts cr		**Reach:**	Downstream
Stream Slope, *S* (ft/ft):	0.00450		**Date:**	
			Practitioner:	
Reach D_{50}, D_{84} (mm):	28	36	**Step D_{84} (mm)[(a)]:**	
Hydraulic Radius, *R* (ft):	1.15			
Mean Flow Depth, *d* (ft)[(b)]:	1.43			
Bedform Variation, σ_z (ft)[(c)]:				
Median Thalweg Depth, h_m (ft)[(c)]:	2.00			
Large Wood in Steps? (y/n)[(c)]:	n			

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 ft/ft (see sheet "S>0.03, Sigma z")

1 Consult Tabular Guidance → **2** Consult Photographic Guidance → **3** Apply a Quantitative Prediction Method

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:	0.030	0.100	y
Estimate from Photographic Guidance:	0.038	0.161	y

Instructions: (See technical summary report, TS-103, for more detailed instructions and references.)

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: I90 MP01621 Trib to Tibbetts cr | **Reach:** Downstream
Slope, *S* (ft/ft): 0.00450 | **Date:** ----
Practitioner: ----

D_{50}, D_{84}, $D_{84,\,step}$ (m):	0.03	0.04	----
R (ft, m):	1.15	0.35	
d (ft^2, m^2):	1.43	0.44	
σ_z (ft, m):	----	----	
h_m (ft, m):	2.00	0.61	

Overall Average n:	0.033
f:	0.122
Quantitative Average n (1):	0.031
f (1):	0.105
Arcement and Schneider (1989) n:	0.039
f:	0.169

3 Quantitative Prediction

Quasi-Quantitative:

Arcement and Schneider (1989)
$$n = (n_b + n_1 + n_2 + n_3 + n_4)m$$

	n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
	0.03	0	0	0.003	0.006	1	0.039	y
	Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergence (3)	Estimate n	Estimate f	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub. (3)	Use in Average? Enter "y"
Yochum et al. (2012) [R^2 = 0.78; f: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	12.11	0.028	0.085	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	y
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002) (4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84}(step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	12.11	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	0.049	0.266	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	12.5	0.035	0.133	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	y
Hey (1979); a = 12.72	9.7	0.030	0.101	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	y
Limerinos (1970) [R^2=0.77]	9.7	0.030	0.102	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	y

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is present and incorporated into the steps, enhancing step heights.

This spreadsheet has been reviewed for accuracy. However, the ultimate responsibility for flow resistance estimates remains with the user.
U.S. Forest Service
National Stream and Aquatic Ecology Center

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name:	I90 MP01621 Trib to Tibbetts cr		**Reach:**	Proposed
Stream Slope, S (ft/ft):	0.00300		**Date:**	
			Practitioner:	
Reach D_{50}, D_{84} (mm):	20	48	**Step D_{84} (mm)[a]:**	
Hydraulic Radius, R (ft):	1.15			
Mean Flow Depth, d (ft)[b]:	1.43			
Bedform Variation, σ_z (ft)[c]:				
Median Thalweg Depth, h_m (ft)[c]:	2.00			
Large Wood in Steps? (y/n)[c]:				

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 ft/ft (see sheet "S>0.03, Sigma z")

1 Consult Tabular Guidance → **2** Consult Photographic Guidance → **3** Apply a Quantitative Prediction Method

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	f	Use in Average? Enter "y"
Tabular Estimate:	0.030	0.100	y
Estimate from Photographic Guidance:	0.038	0.161	y

Instructions: (See technical summary report, TS-103, for more detailed instructions and references.)

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: I90 MP01621 Trib to Tibbetts cr
Slope, *S* (ft/ft): 0.00300

Reach: Proposed
Date: ----
Practitioner: ----

D_{50}, D_{84}, $D_{84,\,step}$ (m):	0.02	0.05	----
R (ft, m):	1.15	0.35	
d (ft^2, m^2):	1.43	0.44	
σ_z (ft, m):	----	----	
h_m (ft, m):	2.00	0.61	

Overall Average *n* :	0.033
f :	0.124
Quantitative Average *n* (1):	0.032
f (1):	0.111
Arcement and Schneider (1989) *n* :	0.038
f :	0.161

3 Quantitative Prediction

Quasi-Quantitative:

Arcement and Schneider (1989)
$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

	n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
	0.03	0	0	0.008	0	1	0.038	y
	Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergence (3)	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub. (3)	Use in Average? Enter "y"
Yochum et al. (2012) [R^2 = 0.78; *f*: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	9.08	0.029	0.096	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	y
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002)(4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84}(step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	9.08	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	0.042	0.196	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	17.5	0.031	0.109	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	y
Hey (1979); a = 12.72	7.3	0.033	0.120	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	y
Limerinos (1970) [R^2=0.77]	7.3	0.033	0.120	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	y

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is present and incorporated into the steps, enhancing step heights.

This spreadsheet has been reviewed for accuracy. However, the ultimate responsibility for flow resistance estimates remains with the user.
U.S. Forest Service
National Stream and Aquatic Ecology Center

Appendix H - Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*SR90 MP 16.21*	**Key piece volume**	***1.310***	*yd3*
Stream name	*Unnamed Tributary to Tibbetts Creek*	**Key piece/ft**	***0.0335***	*per ft strean*
length of regrade[a]	*507 ft*	**Total wood vol./ft**	***0.3948***	*yd3/ft strear*
Bankfull width	*9 ft*	**Total LWM[c] pieces/ft stream**	***0.1159***	*per ft strean*
Habitat zone[b]	*Western WA*			

Log type	*Diameter at midpoint (ft)*	*Length(ft) [d]*	*Volume (yd^3/log) [d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*
A	1.5	*21*	1.37	**yes**	yes	16	21.99
B	1.75	*15*	1.34	**yes**	yes	18	24.05
C	2	*12*	1.40	**yes**	yes	22	30.72
D	2	*18*	2.09	**yes**	yes	24	50.27
E	1.3	*7*	0.32	**no**	no	13	4.14
F	2.3	*13*	1.91	**no**	yes	23	44.03
G	1.0	*14*	0.41	**no**	no	11	4.48
H	2.5	*6*	1.09	**no**	no	19	20.73
I			0.00				0.00
J			0.00				0.00
K			0.00				0.00
L			0.00				0.00
M			0.00				0.00
N			0.00				0.00
O			0.00				0.00
P			0.00				0.00

	No. of key pieces	**Total No. of LWM pieces**	**Total LWM volume (yd^3)**
Design	103	146	200.4
Targets	**17**	**59**	**200.2**
	surplus	surplus	surplus

Appendix I - Reach Assessment

Appendix I has been left blank as no existing reach analysis has been validated to be included in the PHD appendix.

Appendix J - WDFW Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name: 991182

Stream Name: Tibbets Creek

Drainage Area: 93 ac

Projected mean percent change in bankfull flow:

2040s: 15.4%

2080s: 19.8%

Projected mean percent change in bankfull width:

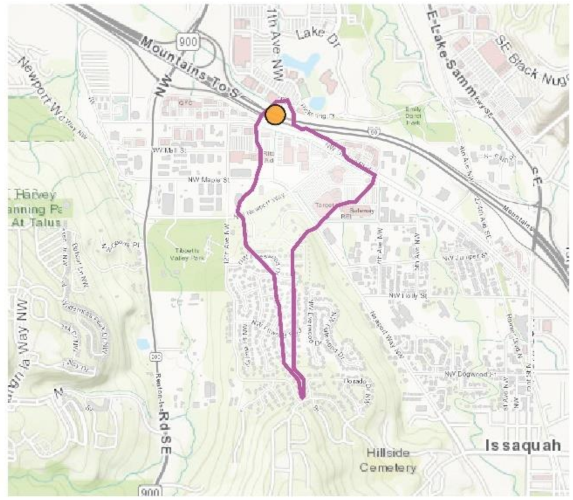
2040s: 7.4%

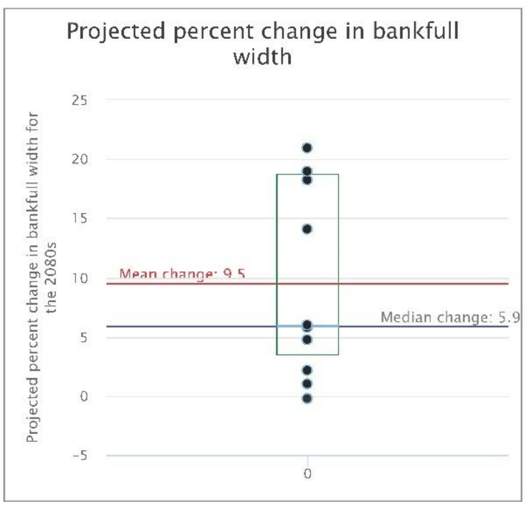
2080s: 9.5%

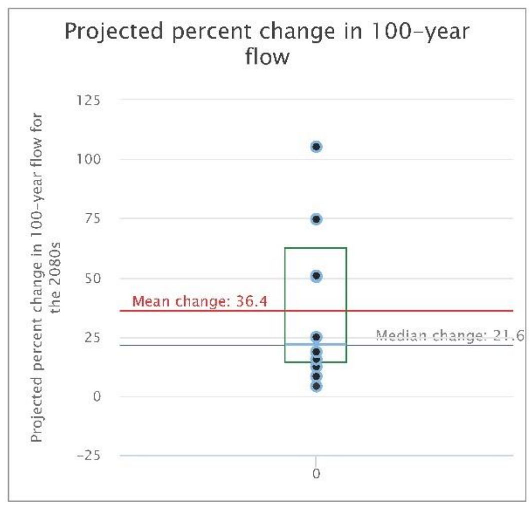
Projected mean percent change in 100-year flood:

2040s: 25.3%

2080s: 36.4%







Black dots are projections from 10 separate models

The Washington Department of Fish and Wildlife makes no guarantee concerning the data's content, accuracy, precision, or completeness. WDFW makes no warranty of fitness for a particular purpose and assumes no liability for the data represented here.